SHORELINE PROCESSES AND COASTAL COMPARTMENTS OF GOLDEN BAY, SOUTH ISLAND, NEW ZEALAND.

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F. J. MUIR

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ABSTRACT

Golden Bay is a broad, shallow, roughly circular embayment over 30 km across. Depths within the bay do not exceed 40 m and the shoreline is formed by a narrow strip of prograded beach ridges, fronted by predominantly sandy beaches and extensive intertidal sand-flats. The coastline is dissected by a number of river mouths and shallow inlets.

Wave energies within Golden Bay are low compared with exposed open-ocean shores elsewhere in New Zealand but the incidence of storm surges coupled with the large tidal range, greater than 4.0 m, means that considerable potential for both foreshore erosion and long-shore transport of sand exist.

Beach sediments are predominantly medium to fine sands that are well to very well sorted. Local deviations from this trend exist due to local sediment sources and hydraulic factors. The protected northern beaches show less volumetric beach change (20-40 m^3/m) than the more exposed southern beaches (40-80 m^3/m). The relatively large amounts of short term volumetric beach change can be accounted for by the large short term sea level variations, associated with tidal variations and storm surges, and the accompanying changing wave conditions.

The major length of the Golden Bay shoreline is stable to prograding; only 9.0 km of coastline are subject to continual or episodic erosion. However these areas are of prime concern to coastal management as these sections are extensively developed for housing and recreation.

There exists within Golden Bay nine coastal compartments which display distinct variations in terms of either marine processes,

beach sediments and morphodynamics or shoreline change. Within three of these larger compartments there exist a number of less exclusive cells which display one common characteristic but may very with respect to these criteria.

CHAPTER ONE
INTRODUCTION

The existence and importance of coastal sedimentation compartments within broader coastal environments has been a strong interest in the literature but the criteria by which they may be defined and described are not always clear. This investigation into the process and morphologic environments of Golden Bay will present an examination of such criteria as they apply in that area. The recognition of distinct coastal compartments within which somewhat distinct sub-systems can be defined is also a useful adjunct for a number of other purpose-orientated studies, for example coastal management policies.

1.1 RESEARCH CONTEXT AND OBJECTIVES

The majority of coastal studies in New Zealand have been carried out in mesotidal, open-ocean swell environments. Little study has been directed to macrotidal, low energy environments. The coastal environment of Golden Bay is distinctive since it has low wave energies, a sandy generally prograded shoreline and a macrotidal range, so that it presents the opportunity to study a rather different coastal environment.

The few previous coastal studies within Golden Bay have been local and purpose-oriented. No attempts have been made to comprehensively study the spatial and temporal variations in beach sediments and morphodynamics, with a view to defining the existence of separate or linked coastal compartments.

A number of coastal erosion problems have arisen or been compounded by development of the Golden Bay shoreline. Therefore the recreational and second home significance provides added justification for a comprehensive investigation of the coastal systems and the defining of beach compartments.

Research objectives for this study have given consideration to these themes and are:

I) To describe the characteristics of the physical process environment, particularly the wind and wave climate and the longshore transport system.

II) To study the spatial variation in beach sediments and beach morphodynamics.

III) To investigate shoreline changes in the recent past, particularly those in the last 100 years.

IV) To define and describe a system of distinct shoreline compartments which may be identified as a result of the investigations into the first three objectives.

1.2 THESIS OUTLINE

Research for this project covered a range of sub-investigations and the organisation of the thesis reflects this.

This first chapter outlines the research objectives and how the following text will proceed in dealing with them.

Chapter Two serves as a background and gathers together relevant information on the Golden Bay coastline from studies completed prior to the present one.

Chapter Three outlines and discusses the important physical process elements of the wind and wave climate and the longshore sediment transport system. The discussion will concentrate on the type, magnitude, frequency and relative significance of each element.

Chapter Four deals with the spatial and temporal variations of the coastal sediments and beach morphodynamics as they occur in response to various marine processes.

Recent shoreline change and the results of man's development on the coastal area are analysed and reviewed in Chapter Five.

Chapter Six defines and describes a sequence of distinct coastal compartments around Golden Bay. This is based on information obtained from the preceding chapters.

The final chapter draws the major conclusions of the thesis together and offers some suggestions for future research.

CHAPTER TWO
THE STUDY AREA

2.1 PHYSIOGRAPHY

Golden Bay is located in the north-west corner of the South Island of New Zealand (Fig. 2.1). The principal areas of study extend from just north of Abel Head to Wainui Inlet.

As can be seen from Figures 2.1 and 2.2 Golden Bay is a broad, shallow, roughly circular embayment over 30 km across. It stretches between the protected lee side of Farewell Spit and the rugged cliffed coast of the Pikikiruna Range, within the Abel Tasman National Park.

Depths within Golden Bay do not exceed 40 m and the general coastal aspect is one of a narrow strip of prograded beach ridges fronted by sandy beaches and extensive intertidal sandflats. The coastline is dissected by a number of river mouths and shallow inlets.

Table 2.1 shows that ocean beaches comprise a significant length of the Golden Bay coastline. It is these beaches which are of prime interest to the thesis. The shoreline within the inlets is generally protected from wave action by enclosing spit formations. The occurrence of numerous inlets suggests that most exposed beaches can be expected to be influenced by their proximity to an inlet. This influence may arise from the presence of tidal deltas, inflow-outflow water exchanges and/or longshore sediment bypassing at the inlet mouth. Thus a feature of the beaches is their close association with potentially large sediment sources such as inlets

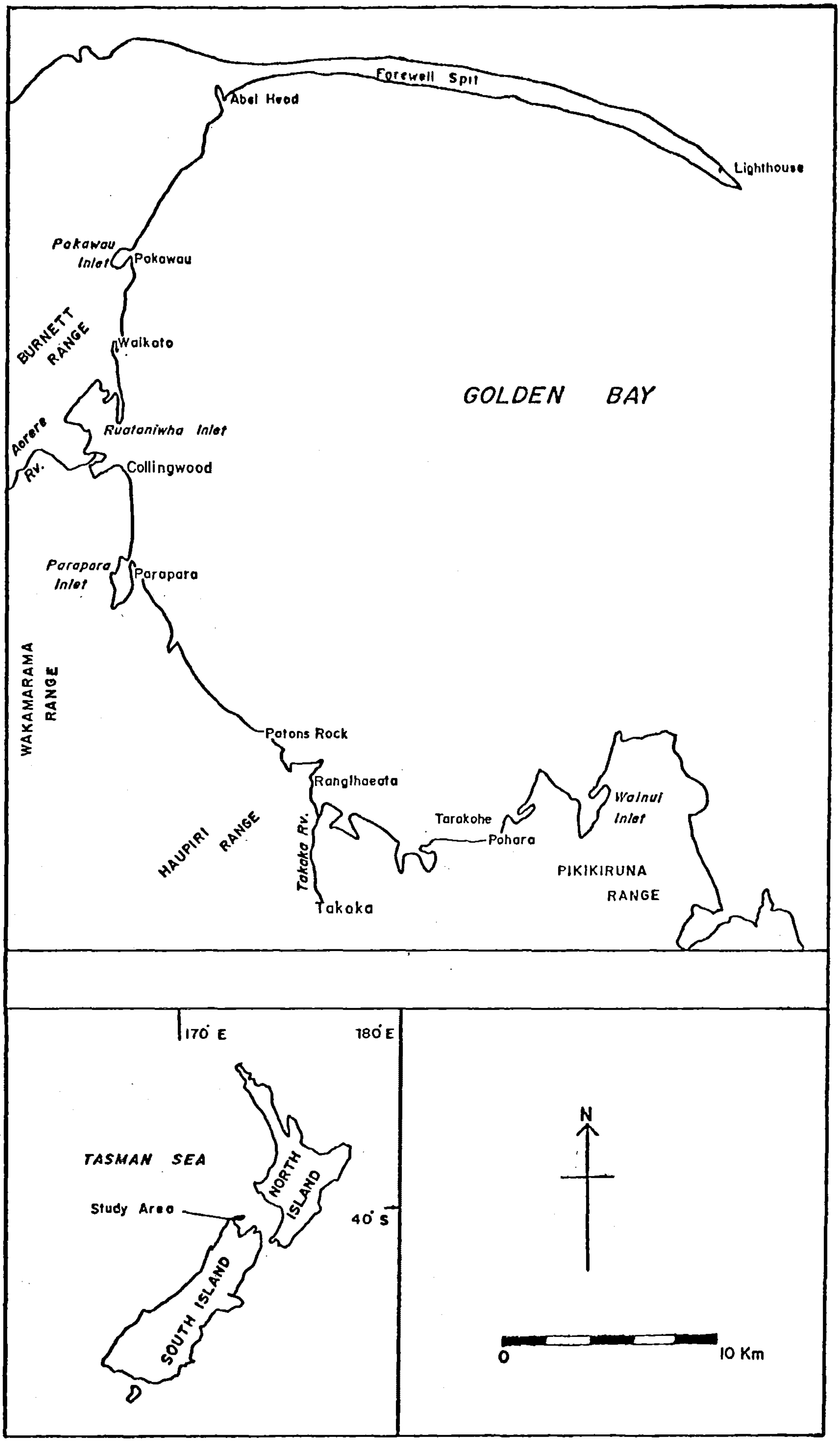


Fig. 2. 1 - Study area location map.

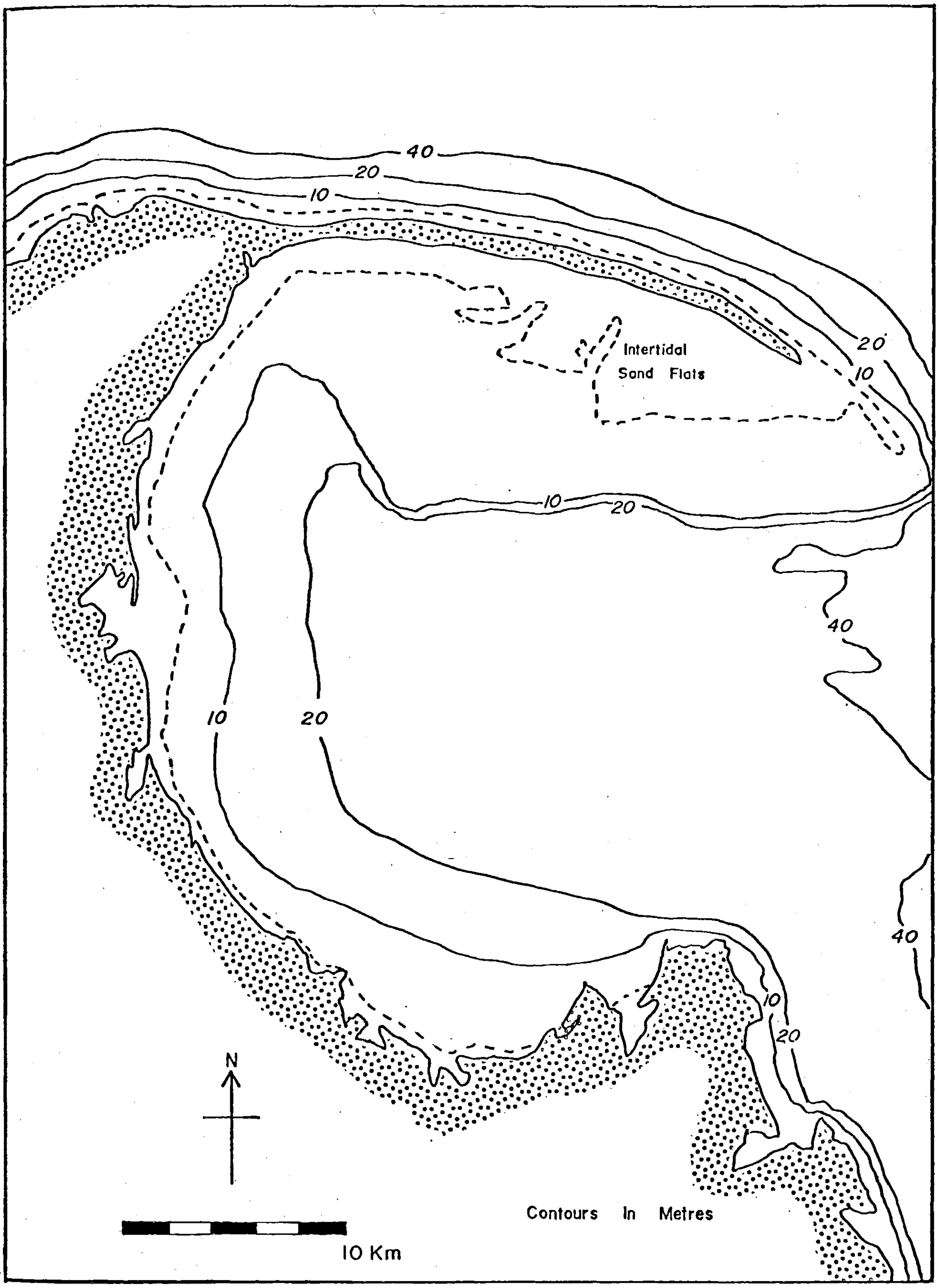


Fig. 2.2 - Golden Bay bathymetry
(Source: Geol. Map N. Z. 1:63,360, Sheets S1, S3, S4 and S8)

Table 2. 1 - Distances and percentages of shoreline in the study area, divided into two main types. (Compiled from 1:63, 360 scale NZMSI sheets S1, S3 and S8.)

Shoreline Type	Shoreline (km)	Distance (%)
(I) Total Exposed Coastline		
(a) Beaches	42	78
(b) Rocky shoreline and cliffs	12	22
Total	54	100
(II) Total Sheltered Coastline		
(a) Inlets	37	100
Total	37	100

or cliffs. Therefore it may be tentatively proposed that the Golden Bay coastline comprises a number of distinct beach compartments each with its own set of sediment sources and sinks.

2.2 GEOLOGIC FACTORS

Geological factors have contributed significantly to the character of the present-day coastline by providing the structural framework upon which the modern coastal morphology has developed.

2.2.1 Rock Units

The rock types outcropping along the shoreline of Golden Bay provide the basement geological framework upon which the present-day morphology has developed. These rocks comprise Paleozoic schists and granites, Tertiary limestones and siltstones, weakly consolidated Pleistocene gravels and unconsolidated Recent beach and dune deposits (Grindley and Watters, 1965). The distribution of these rock types and the basic morphologic structure developed within these rock types is shown in Figure 2.3 and outlined in the following discussion.

Cliffs

Where hard resistant lithologies, granite, limestone and schists, outcrop along the coast precipitous cliffs are developed. The granite coast of Abel Tasman National Park is indented by bayhead beaches lying between cliffed promontories. The weathered granites make up the sediment composition of these bayhead beaches and the beaches of Wainui Inlet, Tata Beach and Ligar Bay. The limestone cliffs found near Tarakahe, Rangihaeata Head and Abel Head are subject to differential weathering and erosion which picks

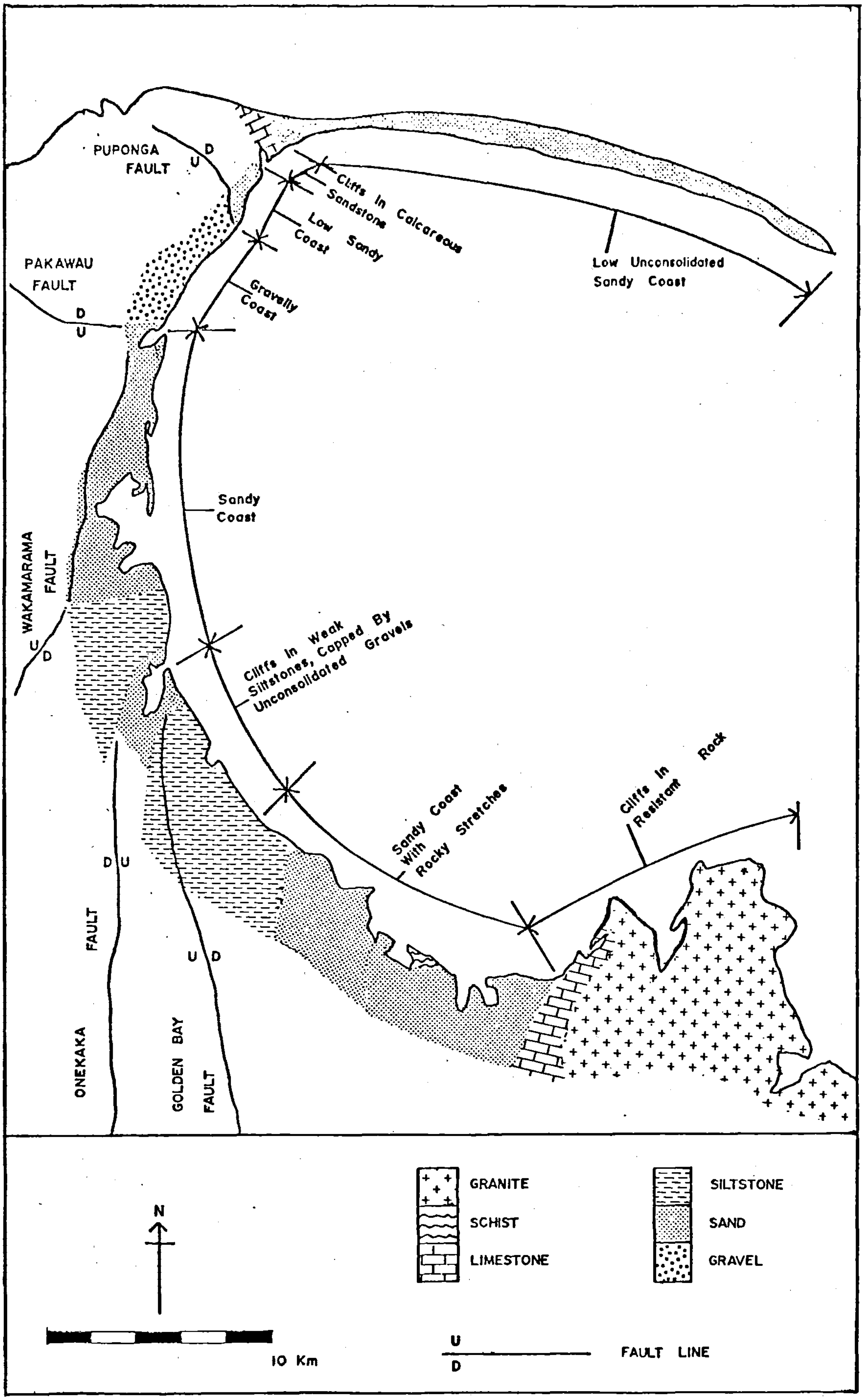


Fig. 2.3 - Geologic rock units that outcrop along the coast. (Source: Geol. Map N.Z. 1:63,360, Sheets S1, S3, S4 and S8.)

out the limestone bedding. This gives rise to numerous benches and notches at approximately high tide level.

The cliffs cut in the weak blue-grey siltstones and mudstones occur continuously along the coast between the Parawhakaoho River and the Onekaka Inlet and discontinuously north past the Onekaka Inlet to Collingwood. The cliffs are only worked by wave runup during high tides. At low tide a fringing shore platform is exposed which is often covered by a thin veneer of sand.

Unconsolidated Sands and Gravels

Much of the shoreline of Golden Bay is characterised by extensive recent accumulations of dune and beach sands which have been supplied in abundance from the Takaka and Aorere Rivers and from the initial erosion of the last post-glacial shoreline. Where gravels, underlying low terraces, are exposed at the coast boulder/cobble/pebble concentrations accummulate on the beach face area. These accumulations are most prolific north of Pakawau but can also be found near some river outlets; for example, the Onekaka River.

2.2.2 Geological Structure - Pre Quaternary

Inland, away from the narrow coastal lowland strip, the region is dominated by the fault-bounded blocks of the Burnett and Wakamarama Ranges, the Parapara and Haupiri Ranges as well to the east by the high land of the Pikikiruna Range in Abel Tasman National Park.

The ranges consist predominantly of a complex of strongly folded metamorphic and volcanic rocks of lower-middle Paleozoic age, which to both east and west are flanked by Upper Paleozoic granite intrusions. Non-marine coal measures overlie these Paleozoic rocks in the Wakamarama Range. Elsewhere around the Golden Bay coast they are overlain by gently folded and faulted Tertiary sediments which are remnants of a once far more extensive cover. The upstanding ranges are separated by the broad terraced valleys in which flow the Aorere and Takaka Rivers. The gravel deposits of these valleys, which reach the coast in numerous places, are of glacial or fluvio-glacial origin. Numerous fault scarps can be followed through the district and traced to the coastline, such as the Wakamarama, Golden Bay, Pakawau and Puponga Faults (Bishop, 1971; Grindley, 1971; Grindley and Watters, 1965).

2.2.3 Late Quaternary History

Radiocarbon dating of shell layers from the continental shelf off the north-west coast of the South Island reveals evidence that suggests that sea level during the last major glaciation, 20,000 years BP, was approximately 100 m below its present position (Norris, 1972). This lower sea level exposed large areas including Golden Bay and the western portions of Cook Strait.

The Aorere and Takaka Rivers contributed large quantities of sediment to the region during this period.

From about 15,000-6,000 BP, sea level rose rapidly to near its present level in what is generally termed the "post-glacial" or "Holocene" transgression. Since 6,000 BP sea level has either been stable or shown small vertical oscillations around the stable position (Chappell, 1975; Curray, 1964; Kirk, 1975; Schofield, 1977; Thom, 1973).

Since the stabilisation of sea level the Golden Bay coastline has been adjusting to the new conditions of sea level, sediment supply and other influencing processes. Examples of coastal adjustment would be the erosion and/or rejuvenation of rocky coastal cliffs and shore platforms, the longshore and shore-normal dispersal of existing fluvial deposits and the formation of coastal deposits, such as the numerous spit complexes around Golden Bay.

2.3 CLIMATIC CHARACTERISTICS

The mid-latitude position of Golden Bay means that the climate is temperate and the global belt of westerly winds exerts a prevailing influence. Associated with this westerly wind belt are weather patterns characterised by successions of anticyclones and depressions which generally move eastward and to the north of the study area. Unsettled weather is often associated with the troughs extending from depressions with changes to southerly or south-westerly winds of cold air as the trough advances north-eastward. These unsettled conditions usually occur between anticyclones (Garnier, 1958).

Unsettled weather conditions may also occur in the study area as very intense depressions move south off the west coast of the North Island. These depressions may cause strong north-easterly winds in the vicinity of Golden Bay as they pass by. The most intense of these systems are the remnants of tropical cyclones which may pass into the area, usually in the spring-summer period but they also occur later in the year.

A more detailed discussion of the significant wind regimes will be carried out in Chapter Three where the analysis of wind data is of prime importance to the discussion of the wave climate.

The mean annual precipitation varies around Golden Bay from 1300 mm at the Farewell Spit lighthouse to 1900 mm at Takaka and 1600 mm at Tarakohe Harbour (N. Z. Met. Service Summary Reports). Only 20% of the yearly rainfall falls in the summer months; the remaining 80% of the annual precipitation is evenly distributed through the following autumn, winter and spring months.

Rainfall may affect the coastal system both directly and indirectly. Directly the rainfall may cause saturation of the beach sediment and elevation of the beach water table. Indirectly the rainfall may cause increased water and sediment discharge as a result of hinterland catchment conditions. Therefore the water and sediment discharge may be less in the summer months as a result of less rainfall in this period. Information available on the water flow rates of the Aorere and Takaka Rivers (pers. comm. 1979, K. Shirley, Nelson Catchment Board), suggests that the Aorere River discharges considerably more water than the Takaka River. The large ebb tide delta built at the mouth of the Aorere River suggests considerable sediment is also discharged.

2.4 OCEANOGRAPHY

2.4.1 Tidal Flows

Flows with tidal periodicity dominate the flow field in Golden Bay. The two main tidal constituents around New Zealand, the principal lunar and solar semi-diurnal tidal components, have about their largest amplitudes in the Golden and Tasman Bay region (Heath, 1976b). In consequence the spring tidal range and difference between spring and neap tidal ranges are amongst the largest in New Zealand. The spring tides have a range of approximately 4.2 m, while neap tidal ranges are in the order of 2.4 m (Mar. Div., MOT, 1979).

Tidal current speeds have been measured by a number of researchers in this area. Heath (1973) reported speeds of 0.05-1.0 ms^{-1} which were calculated from drift card recoveries. Surface current speeds of up to 0.5 ms^{-1} were observed by Ridgway (1977). Measurements of the ebb and flood tides at Tarakohe (Morris and Wilson, 1976) show that the flood tide obtained a slightly higher speed; the maximum velocity measured was 0.24 ms^{-1}. All studies reveal that current speeds are generally smaller at the bottom than at the surface. The differences in velocities between the bottom and surface currents would result partly from frictional effects and from wind induced movement on the surface. The direction of the tidal flow is generally parallel to the coastline, but the surface flow may be strongly influenced by the wind direction.

Despite the relatively slow speed of the currents they are significant when considered as a mechanism for transporting sediment in suspension, especially if coupled with the turbulence created by waves.

2.4.2 The Mean Circulation

Studies carried out by Brodie (1960) and Heath (1969) report that the surface current entering Golden Bay is derived from the north flowing surface current of the west coast of the South Island and the D'Urville Current (Fig. 2.4). At Separation Point this current branches, one branch flowing west into Golden Bay where it forms into a clockwise flow; the other branch flows south-east into Tasman Bay. Further studies by Heath (1973 and 1976) and sedimentological studies by van der Linden (1968) support these early findings.

Surface circulation is dependent on the wind system existing in the area. Heath (1973) showed that the direction of the surface circulation is not constant. During northerly winds the predominate flow is to the head of the Bay, while during southerlies the flow is out of the Bay. Typical mean speeds calculated for the circulation system by Heath (1976b) and Ridgway (1977) show speeds in the order of

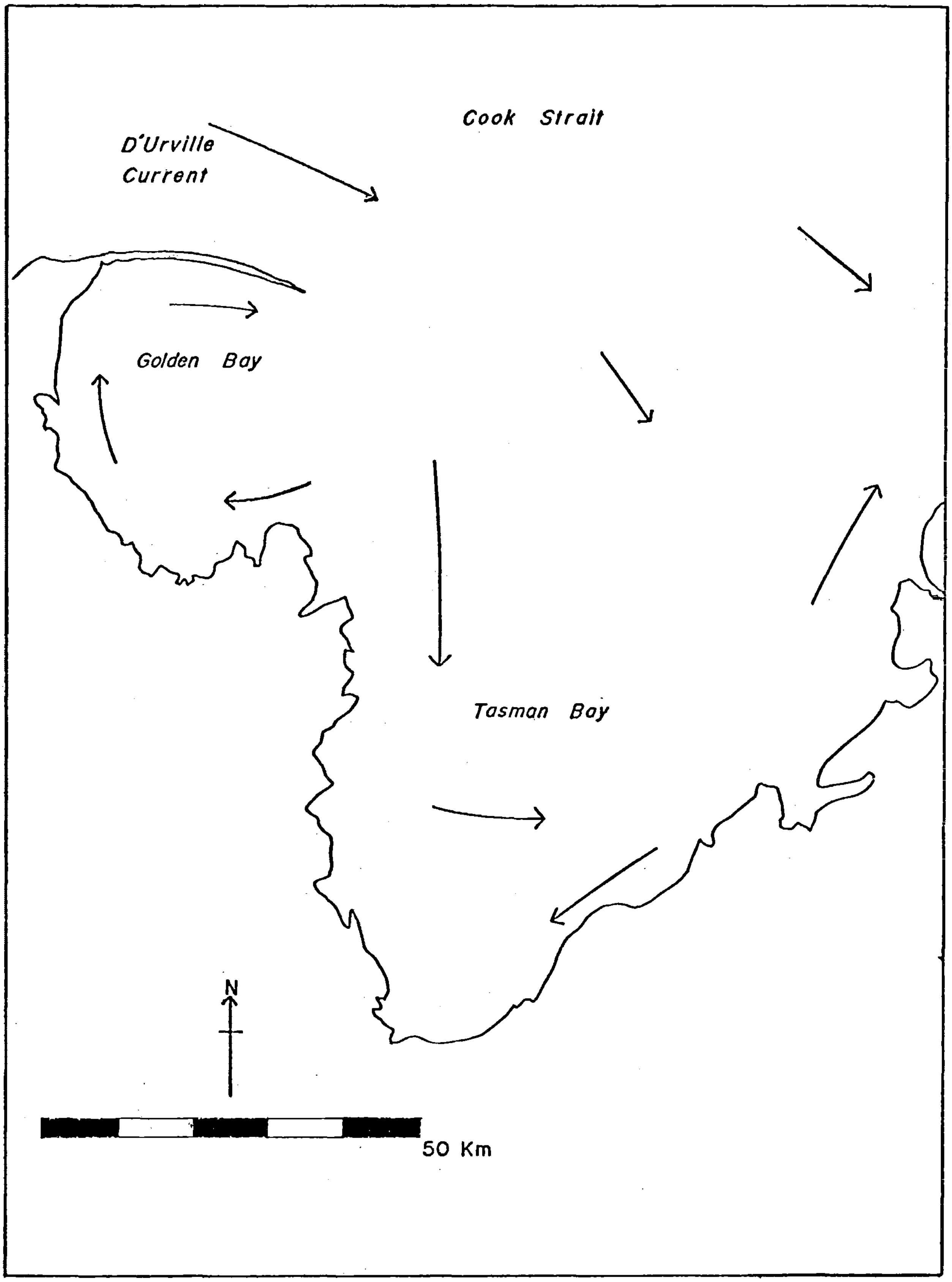


Fig. 2.4 - Direction of mean circulation in Golden and Tasman Bays.
(Source: Heath, 1976a)

of 0.02-0.05 ms^{-1} which are less than those measured for the tidal flows.

2.4.3 Hydrologic Factors

The temperature and salinity values in Golden Bay are typical of subtropical waters. In summer these values are typically 20°C and 35‰ respectively. Water temperatures increase shorewards in summer. A strong thermocline is developed, a zone in which the change in temperature with depth exceeds 1°C per metre, due to the effect of insolation. In winter water temperatures fall to 11°C and the surface salinities are reduced by the influx of freshwater runoff producing a large vertical salinity contrast (Heath, 1976a; Ridgway, 1977).

Heath (1976a) calculated the residence time of water in Golden Bay by several methods. Summarising he calculated that the residenc time of water in Golden Bay is governed by the mean circulation with enhancement by the tides and fluctuating winds. The residence time would appear to be between one and three months.

2.5 SUMMARY

This chapter has presented a review and synthesis of information on a variety of subjects which provide relevant background information for the following chapters.

The present-day physical setting of Golden Bay is a result of geologic events which have fashioned the inland and coastal Golden Bay areas. The inland area was primarily formed in pre-Quaternary times, while the form of the present-day coatline is a result of post-Quaternary events. The various physical features that exist around the Golden Bay coastline, cliffed coasts, inlets and sandy beaches, suggest that the coastline may be comprised of a number of distinct compartments.

The weather systems influencing the Golden Bay area control the wind climate and resulting wave environments, that will be discussed in Chapter Three. Rainfall data suggests a lower period of precipitation in the summer and the remainder of the annual precipitation is evenly distributed through the rest of the year. Water discharge rates from the Aorere and Takaka Rivers are probably less in the summer and so sediment supply may be less in this period.

The tidal regime dominates the flow field in Golden Bay, with large tidal ranges and large differences between neap and spring tides. The mean circulation within Golden Bay is predominantly in a clockwise (westerly) direction. Ocean current velocities have been found to be smaller than those measured for tidal currents. Temperature and salinity factors show a distinct seasonal variation; the temperature of the water falls during the winter and the salinity of the water decreases during this period due to increased freshwater runoff. The residence time of water in Golden Bay would appear to be one to three months.

CHAPTER THREE
COASTAL PROCESSES

3.1 INTRODUCTION

Previous studies of New Zealand coasts have concentrated on open-ocean swell and storm wave environments. The wave environment of Golden Bay is not of this type since there are restricted fetches to north and north-east and the bay is protected to some degree from westerly waves arriving from the Tasman Sea by Farewell Spit.

The following discussion on the coastal processes will evaluate the magnitude, frequency and significance of these processes in Golden Bay.

3.2 THE WIND CLIMATE

Golden Bay lies at latitude 41^{o} South and is therefore strongly influenced by westerly winds. The various wind patterns are the result of characteristic weather patterns which pass through this region. The wind climate of the study area may be determined from the frequency of occurrence of the weather systems, described in Chapter Two, and by the seasonal distribution of these systems.

Wind data available for this study came from two climatological stations. The first is located at the distal (northern) end of Farewell Spit and recordings are available for the years 1961 to 1978. The second station is located at Tarakohe Harbour (Fig. 2.1) and the data represent only a limited period of 11 months, June 1978 to April 1979.

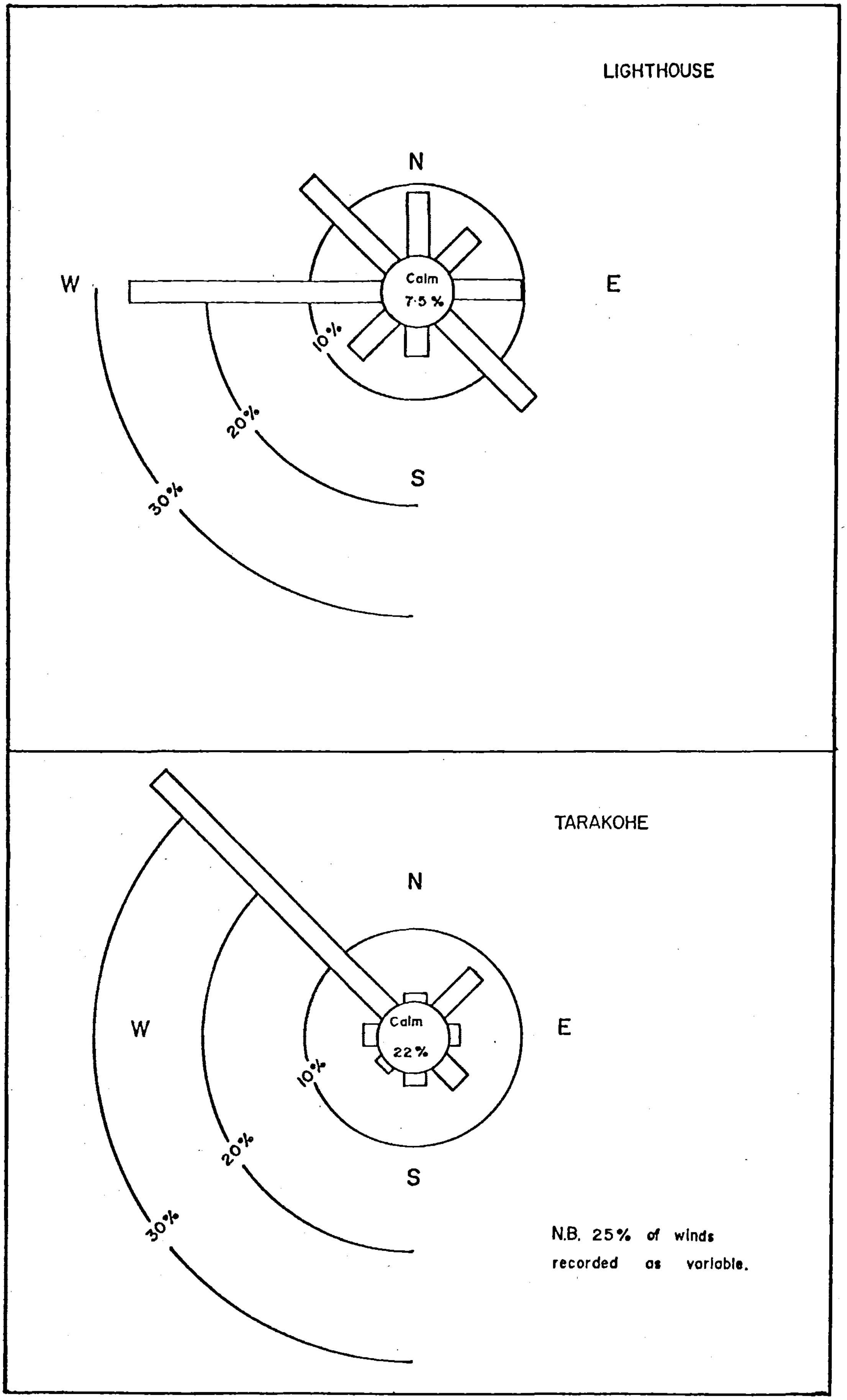


Fig. 3. 1 - Percent frequency of winds at Farewell Spit lighthouse and at Tarakohe Harbour.
(Source: N. Z. Met. Service)

As Figure 3. 1 shows Tarakohe is subject to a higher proportion of calm and variable conditions than Farewell Spit, due to its sheltered physical setting. Owing to this fact and also that the data recorded at Farewell Spit represent a much longer period, the Farewell Spit recordings will be used to establish the main features of the wind environment. The variations in wind direction recordings as shown by Figure 3. 1 suggests that wind directions probably vary a great deal around the shoreline of Golden Bay owing to topographic and physiographic variations.

With respect to wave generation, propagation and shoreline processes, the following discussion may be summarised from Figure 3. 1 and Tables 3. 1, 3. 2 and 3. 3.

Approximately 70% of all winds at Farewell Spit are from directions in which wave generation is possible, that is, north, north-east, east, west and north-west sectors. Generally the prevailing wind conditions within Golden Bay can be expected to produce very calm sea conditions.

North-west and westerly winds predominantly blow at low velocities but may blow at high velocities for short periods of time and over limited fetch areas. North and nort-easterly winds may also occasionally blow at high velocities, but over greater fetch lengths.

A seasonal distribution of wind conditions is evident from the tables. The higher velocity winds from the north-west and north-east, which are likely to produce rougher sea conditions, are more frequent in the spring and summer months. The autumn and winter period is subject to a greater frequency of calm conditions and off-shore winds which should result in calmer sea conditions.

Table 3. 1 - Monthly frequency of winds from various directions. (Source: N. Z. Met. Service)

Month	Direction								Calm	Total
	N	NE	E	SE	S	SW	W	NW		
January	9. 1	8. 5	11. 5	7. 5	1. 7	4. 8	32. 1	19. 6	5. 2	100
February	10. 5	9. 1	12. 8	9. 9	2. 3	4. 6	26. 3	17. 4	7. 0	100
March	9. 4	9. 0	10. 4	13. 4	2. 4	6. 4	23. 7	17. 5	7. 9	100
April	8. 5	7. 1	11. 2	12. 1	5. 1	7. 9	27. 0	12. 5	8. 7	100
May	6. 5	5. 5	8. 5	15. 2	7. 2	10. 7	27. 4	10. 7	8. 3	100
June	5. 3	3. 7	6. 6	20. 4	9. 8	11. 6	24. 9	7. 8	9. 8	100
July	6. 2	5. 1	9. 3	20. 4	9. 6	8. 9	23. 3	8. 8	8. 5	100
August	8. 6	6. 1	10. 2	19. 4	8. 1	7. 7	21. 6	10. 4	8. 0	100
September	9. 6	6. 0	8. 4	12. 7	5. 3	7. 9	29. 2	14. 0	7. 0	100
October	8. 6	6. 8	6. 2	7. 1	2. 6	7. 7	35. 7	19. 3	5. 9	100
November	9. 8	8. 2	6. 9	7. 8	2. 0	5. 8	34. 6	20. 1	4. 8	100
December	9. 5	9. 8	7. 5	6. 9	3. 0	5. 4	33. 1	18. 9	5. 9	100

Table 3. 2 - Monthly frequency of wind speeds (kts).
(Source: N. Z. Met. Service)

Month	Speed (kts)						Total
	0-3	4-10	11-16	17-21	22-27	+28	
January	5. 8	41. 6	25. 0	12. 5	8. 6	6. 5	100
February	6. 7	46. 4	22. 6	12. 0	7. 7	4. 6	100
March	5. 9	47. 6	23. 3	12. 5	6. 8	3. 9	100
April	6. 5	46. 5	23. 0	13. 2	6. 4	4. 4	100
May	7. 9	45. 4	21. 6	12. 9	6. 7	5. 5	100
June	10. 3	48. 0	20. 8	11. 4	5. 7	3. 8	100
July	8. 9	47. 2	20. 5	12. 7	5. 4	5. 3	100
August	8. 1	46. 3	21. 4	10. 9	7. 1	6. 2	100
September	5. 7	41. 7	21. 6	15. 4	9. 6	6. 0	100
October	4. 9	34. 0	25. 8	16. 9	10. 8	7. 6	100
November	4. 2	33. 6	26. 5	17. 6	9. 5	8. 6	100
December	5. 6	40. 7	25. 1	14. 6	9. 5	4. 5	100

Table 3. 3 - Frequency of wind speeds (kts) by direction.
(Source: N. Z. Met. Service)

Direction	Speed (kts)					
	1-3	4-10	11-16	17-21	22-27	+28
N	0. 69	4. 02	1. 90	1. 04	0. 70	0. 76
NE	0. 63	3. 88	1. 50	0. 57	0. 35	0. 18
E	0. 97	5. 50	2. 20	0. 90	0. 29	0. 25
SE	1. 03	7. 0	3. 10	1. 50	0. 61	0. 40
S	0. 89	2. 90	0. 71	0. 38	0. 24	0. 16
SW	0. 74	3. 80	1. 24	0. 77	0. 70	0. 63
W	1. 30	9. 50	7. 70	5. 85	3. 90	2. 45
NW	0. 60	5. 90	4. 70	2. 50	1. 20	0. 83

In terms of wave generation, the height and period of the wave type is a function of wind velocity, V, fetch length, F and the duration the wind blows from that direction, D; that is $H, T = f(V, F, D)$. The data available for this classification of wave climate, based on wind data, is only concerned with the velocity of the wind and the fetch length. The period the wind blows from a specific direction may only be ascertained for an annual rate, as detailed by Figure 3. 1.

3. 3 THE WAVE CLIMATE

The data for this discussion have been summarised from daily observations of the sea conditions recorded by the Harbour-Master at Tarakohe and secondly from wave information presented in the Morris and Wilson (1976) report on the development of Tarakohe Harbour. A number of limiting factors made any comprehensive survey of wave conditions by the author difficult. These factors include the broad field study area, the large tidal range of Golden Bay and a low wave energy environment.

Figure 3. 2 and Tables 3. 4 and 3. 5 summarise the wave data as recorded at Tarakohe. The following outline of the wave climate is based on these tables and graph.

Wave heights are predominantly below 0. 1 m, nearly 70% of the time. Morris and Wilson (1976) give a comparable figure of 64% for the proportion of time the wave height was below 0. 15 m for the year 1976. These low wave heights are associated with calm and variable conditions and also with the low velocity north-west winds.

The rougher sea conditions are shown to be associated with high velocity westerly and north-westerly winds. As these winds blow over a limited fetch and still produce rough seas the wind velocity and

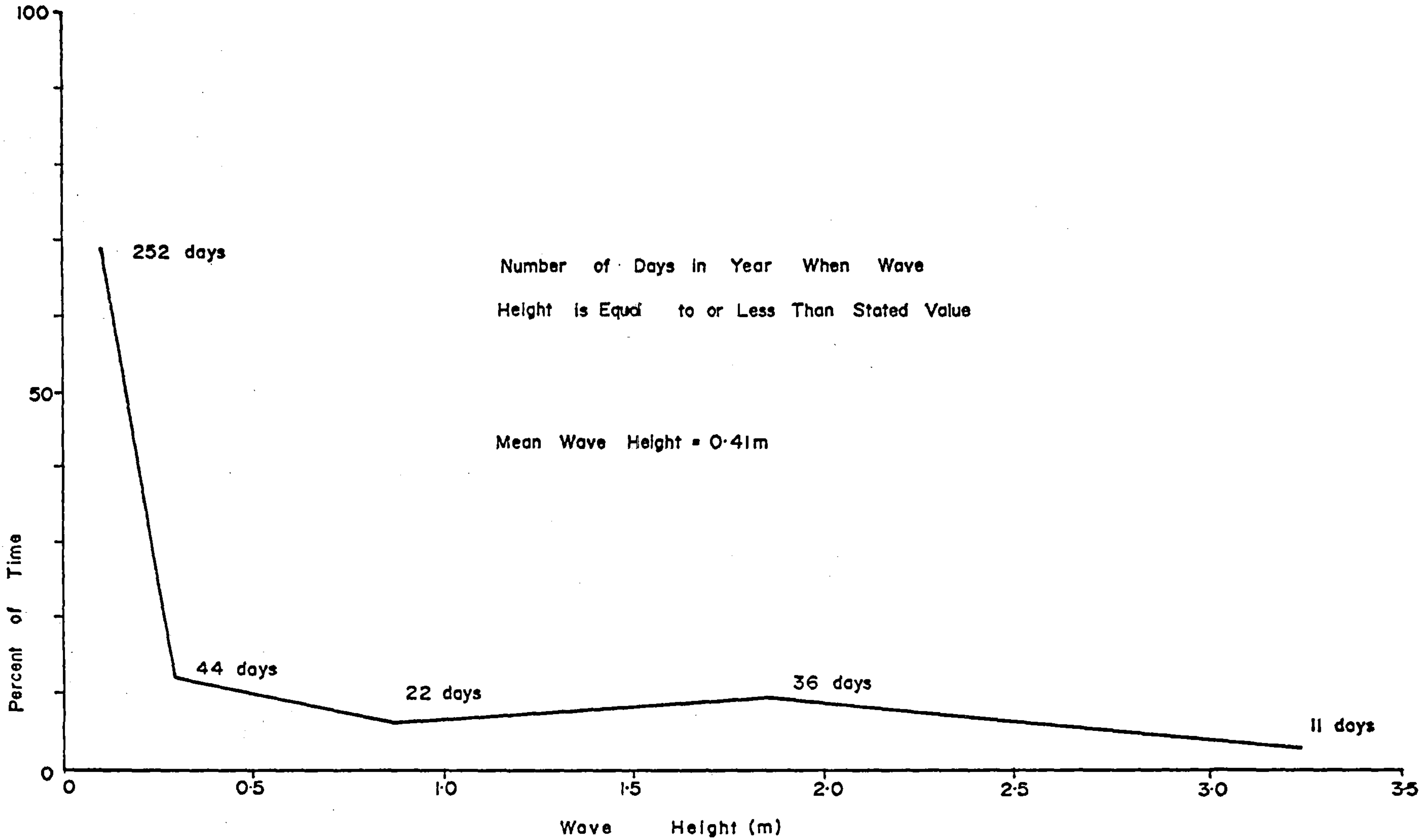


Fig. 3.2 - Percent frequency of wave heights. (Source: N. Z. Met. Service)

Table 3.4 - Percent occurrence of sea conditions in relation to wind direction. (Source: N. Z. Met. Service)

	Sea Conditions (m)				
Wind Direction	Glassy <0.1	Smooth 0.1-0.25	Slight 0.25-1.25	Moderate 1.25-2.5	Rough 2.5-4.0
Calm	31	5	0	0	0
Variable	33	23	0	0	0
W	0	0	0	3	20
NW	21	51	55	94	70
N	3	0	8	0	0
NE	10	3	25	0	0
SE	2	18	12	3	10

Table 3.5 - Seasonal summary of sea conditions (percentage). (Source: N. Z. Met. Service)

	Sea Conditions (m)				
Month	Glassy <0.1	Smooth 0.1-0.25	Slight 0.25-1.25	Moderate 1.25-2.5	Rough 2.5-4.0
January	52.5	15.0	0	22.5	10.0
February	44.0	14.0	12.0	18.0	12.0
March	70.0	15.0	11.0	4.0	0
April	77.0	2.0	9.5	11.5	0
May	No Records				
June	90.5	95.0	0	0	0
July	86.0	14.0	0	0	0
August	82.0	18.0	0	0	0
September	84.0	16.0	0	0	0
October	71.0	9.0	0	20.0	0
November	75.0	5.0	0	20.0	0
December	100.0	0	0	0	0

the duration it blows must be significant components in the wave generation. Table 3.4 does not show the influence of rough seas generated from north-easterly winds. This is because the weather conditions responsible for these rougher seas are independent of local weather conditions and hence of winds recorded at Tarakohe.

The seasonal summary of sea conditions (Table 3.5) supports the summary findings of the wind data. Calm sea conditions predominate all year round but there is a greater occurrence of calm conditions in the autumn-winter period. The rougher sea conditions tend to occur with greater frequency in the spring-summer months.

There are two storm-wave components within Golden Bay. The storm waves generated from the north-west direction are steep, short period waves due to their generation over a limited fetch, 30 km. Wave hindcasting presented by Morris and Wilson (1976) shows a theoretical significant wave height of 2.75 m and periods of 2 to 6 seconds. These figures are based on extreme weather conditions for designing breakwaters. North-easterly storm waves generated in Cook Strait have a significant wave height of 5.50 m and a period of 12 seconds. These waves forecasts are also for extremes in weather conditions. The north-west storm waves occur more frequently than the north-east waves.

The record of sea conditions at Tarakohe is by no means complete and offers only an indication of sea conditions over a short period of time. The data is the only information available and they do provide sufficient detail to form a summary of the influencing wind and wave climate.

3.4 SUMMARY AND SIGNIFICANCE OF WIND AND WAVE DATA.

A distinct seasonal pattern may be proposed based on the wind and wave data analysis.

Spring-Summer (September, October, November, December, January, February)

This is a period which is influenced by weather systems and winds which blow at velocities sufficient to cause rough sea conditions. These winds are north-westerlies generated over a shorter fetch length but of high velocity and possibly long duration. The north-east wave is generated over a longer fetch and is associated with weather systems outside the Golden Bay area.

Autumn-Winter (March, April, May, June, July, August)

This period of the year is subject to a greater frequency of calm and variable conditions which result in calmer sea conditions. The incidence of storm wave conditions is less than during the spring-summer period.

As discussed by Davies (1972) and by King (1972) beach erosion occurs under storm sea conditions while beach accretion occurs under low swell wave conditions. On this basis the Golden Bay coastline can be expected to display the following beach responses, based on wind and wave data.

Periods of beach accretion should occur all year round, especially in the autumn-winter period. This pattern may be interrupted by beach erosion at times when the coastline is influenced by north-west or north-east storm waves. As shown by the analysis of wind and wave data beach erosion is thus more likely to occur in the spring-summer period.

This suggests a seasonal pattern quite different from that identified in the literature, which is usually one of summer accretion and winter erosion. This hypothesis will be examined further in the discussion of short term beach changes in Chapter Four.

3.5 SHORT TERM SEA LEVEL VARIATIONS

3.5.1 Tidal Variations

Temperal variations of sea level in Golden Bay occur with different magnitudes and frequencies depending upon the cause of the variation. The sea level change associated with the semi-diurnal tide and the neap and spring tides are the most frequent sea level variations in Golden Bay.

The tidal range in Golden Bay varies from two to over four metres. As stated earlier, the spring tides have a range of approximately 4.2 m while neap tides have a range of approximately 2.4 m (Mar. Div., MOT, N.Z., 1979). Thus the sea level during spring tides may extend 0.9 m vertically further up the beach and further down below mean low water than during neap tides. This is of significant relevance to beach dynamics should storm wave conditions occur on top of spring tides.

2.5.2 Short Term Meteorological Effects

High water levels may be generated at the shore by local influencing weather situations or by the storms moving south off the west coast of the North Island.

The strong winds which generate the short steep north-west storm waves also generate high water levels (setup). Wind setup is primarily a result of wind stresses on the surface of the water which create a vertical rise in the water level (CERC, Vol. III, 1973). Wave setup, which is defined as the elevation of the still water level at the shoreline (CERC, Vol. III, 1973), is caused by wave action alone. An estimate of the magnitude of the wave setup, for high and low energy waves, can be obtained by using the following equation and wave characteristics (CERC, Vol. I, pp 3-81, 1973).

$$Sw = 0.19 \left\{ 1 - 2.82 \left(\frac{Hb}{gr^2} \right)^{\frac{1}{2}} \right\} Hb$$

where: Sw = Setup Height (feet)

Hb = Wave Breaker Height (feet)

T = Wave Period (seconds)

g = Acceleration of gravity, 32 ft sec^{-2}.

(Answers converted to metric)

For low wave energy waves from the north-west, where Hb = 0.36 m and T = 6 seconds, the setup is 0.062 m. For storm waves associated with the depressions moving south off the west coast of the North Island, where Hb = 3 m and T = 12 seconds, the setup is 0.5 m. Therefore the wave setup due to storm waves is significantly greater than the setup due to low energy waves, which generally prevail in Golden Bay.

The north-east storm waves may also be associated with storm surge. The storm surge results from the combined effects of low barometric pressures and wind setup. The magnitude of the surge also depends upon the seabed bathymetry and the storm's motion.

The general equations used to ascertain storm surge, based on the above factors, are shown below (CERC, Vol. I, Fig. 3.51 to 3.54 and Equation 3.71, pp 3-106, 1973).

$Sp = Si \cdot Fs \cdot Fm$

where: Sp is the predicted peak storm surge (feet)

Si is the peak surge based on storm intensity using the equation $S\Delta p = 1.14\,(pn-po)\,(1-e^{-R/r})$ (feet)

Fs is the bathymetric shoaling factor

Fm is the storm motion factor.

(Answer is converted to metric)

The equation was applied to a typical storm moving south off the west coast of the North Island (Fig. 3.3) which had a central pressure of 980 mb, a storm radius of approximately 400 kms and a distance to shore of 320 kms. Its track speed was approximately 84 kms per hour. The resulting surge calculated for these dimensions was 0.43 m. Heath (1977) found that open-ocean surges in New Zealand are generally in the order of a 0.6 m maximum.

When the surge of 0.43 m is combined with a wave setup of 0.5 m, then a total water elevation of 0.93 m above the predicted tide can be produced. This water elevation will be even greater if it occurs on peak of a spring tide, and thus may be in the order of a 1.8 m water level rise.

3.6 SIGNIFICANCE OF SEA LEVEL RISES

The appreciable vertical sea level changes which can occur as a result of storm conditions may have a pronounced impact on the Golden Bay coastline. The Golden Bay coast is unusual in that it has low wave energies but extreme water level variations. These features can be expected to be reflected in the patterns of change in beach morphology.

The literature proposes two separate elements to account for beach erosion (Bruun, 1962; Dubois, 1975, 1976; Kana, 1977;

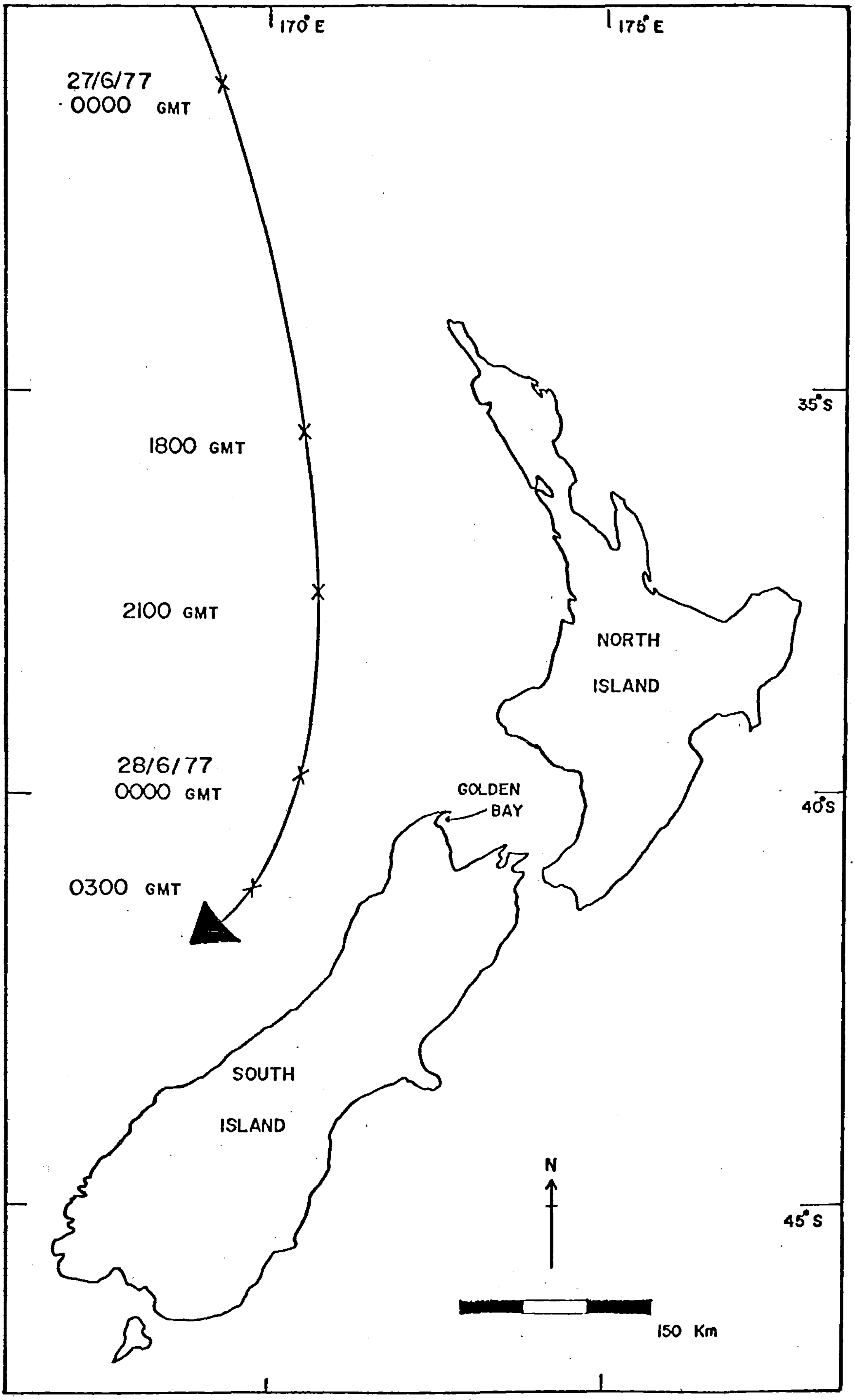


Fig. 3.3 - Track of depression, for which storm surge in Golden Bay has been calculated.

Schwartz, 1967, 1968). First of all wave steepness which is seen as occurring over a short term and secondly sea-level rise which is seen as longer term. In Golden Bay these two elements both operate at the short term scale and with a distinct seasonal aspect. Thus water level variations which accompany changing wave conditions may account for significant beach cut and fill sequences.

The greater variation in sea-level and associated storm waves is likely to occur during the spring-summer months when the high velocity north-west and north-east winds are more common. Thus greater variations in beach morphology may occur during these months. In contrast the sea level rise accompanying the low energy north-west waves, which predominate in the autumn and winter may result in less significant beach morphology change.

3.7 SPATIAL VARIATION IN WAVE REFRACTION COMPONENTS

With respect to the significant wave regimes operating in Golden Bay, wave refraction diagrams can be constructed. Refraction is the process by which the direction of a wave moving in shallow water at an angle to the contours is changed. The part of the wave advancing in shallow water moves more slowly than that part still advancing in deeper water, causing the wave crest to bend toward alignment with the seabed topography (CERC, Vol. I, III, 1973).

In practice, refraction is important for several reasons. Firstly, refraction, coupled with shoaling, determines the wave height in any particular water depth for a given set of incident deepwater wave conditions. Secondly, the change of wave direction of two different parts of the wave results in convergence or divergence of wave energy, and consequently an increase or decrease in wave energy respectively

(CERC, Vol. I, 1973). Therefore the construction of wave refraction diagrams makes it possible to determine zones of relatively higher and smaller wave heights and energy and longshore currents along a section of the coastline.

Wave refraction diagrams were constructed for Golden Bay with respect to the following wave environment conditions, using the method outlined in CERC (Vol. I, pp 2. 65-2. 78, 1973).

(1) North-West waves of 6 second period (Fig. 3. 4)

(2) North-East waves of 12 second period (Fig. 3. 5)

(3) North-East waves of 6 second period (Fig. 3. 6)

3. 7. 1 Spatial Variation in Wave Energy.

The relative amount of convergence or divergence, increase or decrease in relative wave energy and wave height, due to wave refraction, is calculated by the following formula (CERC, Vol. I, 1973).

$$Kb = \left(\frac{Sd}{Sb}\right)^{1/3} \Leftarrow ?? \text{ isn't correct formula} \Rightarrow Kb = \left(\frac{Sd}{Sb}\right)^{1/2} \text{ see (C.E.R.C, Vol. I 1973 p. 2-67)}$$

Where: Kb = wave refraction factor at breaker point

Sd = initial distance between orthogonals

Sb = distance between same orthogonals of refracted wave at breakpoint.

The orthogonals, on the wave refraction diagram, are lines drawn perpendicular to the wave crest. These lines represent the degree of convergence or divergence. If divergence or decrease in relative wave energy has taken place, through refraction, the Kb factor will be less than 1. Conversely is the Kb factor is greater than 1 an increase in relative wave energy has resulted through refraction.

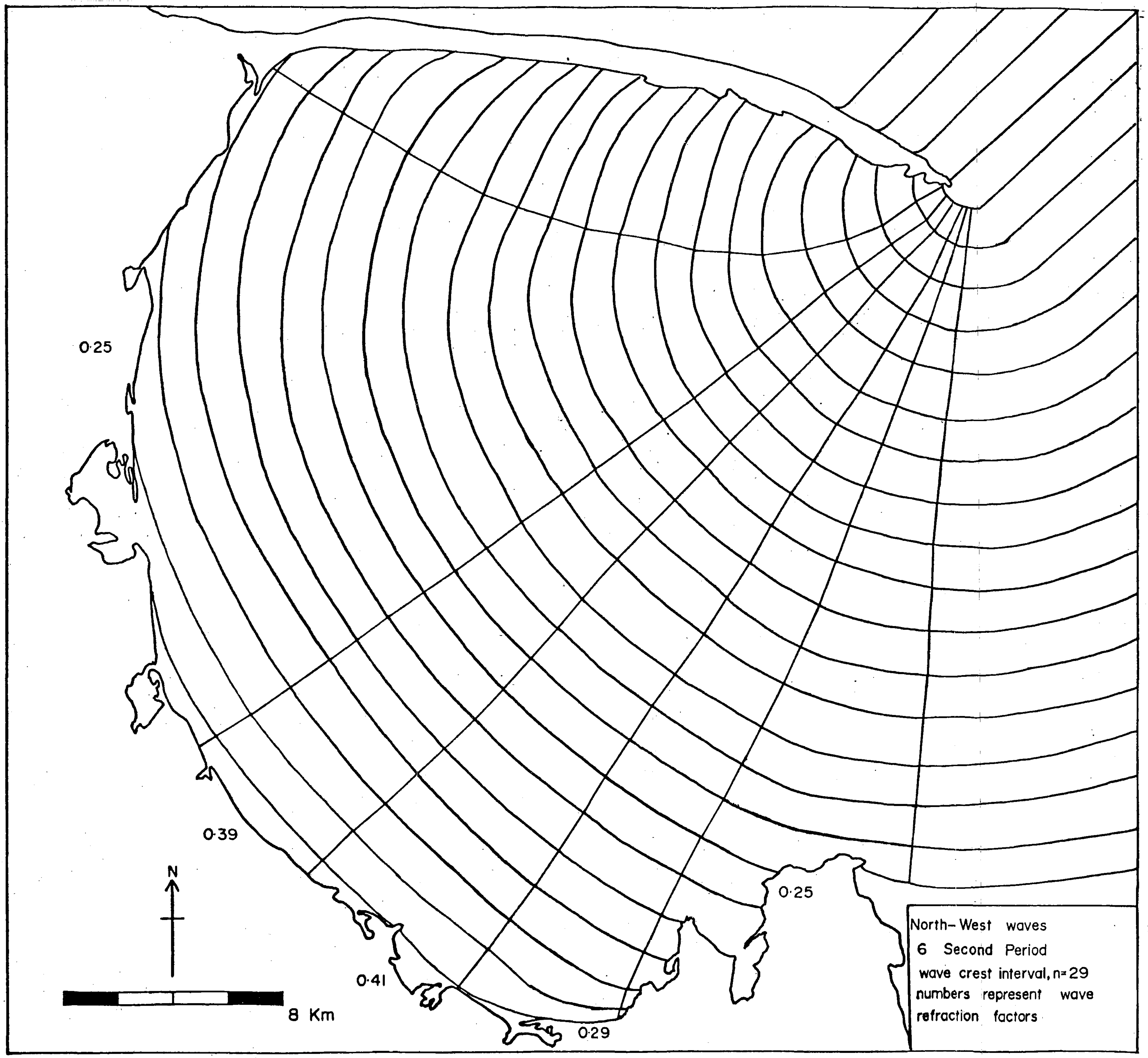


Fig. 3.4 - Wave refraction for North-West waves of 6 second period.

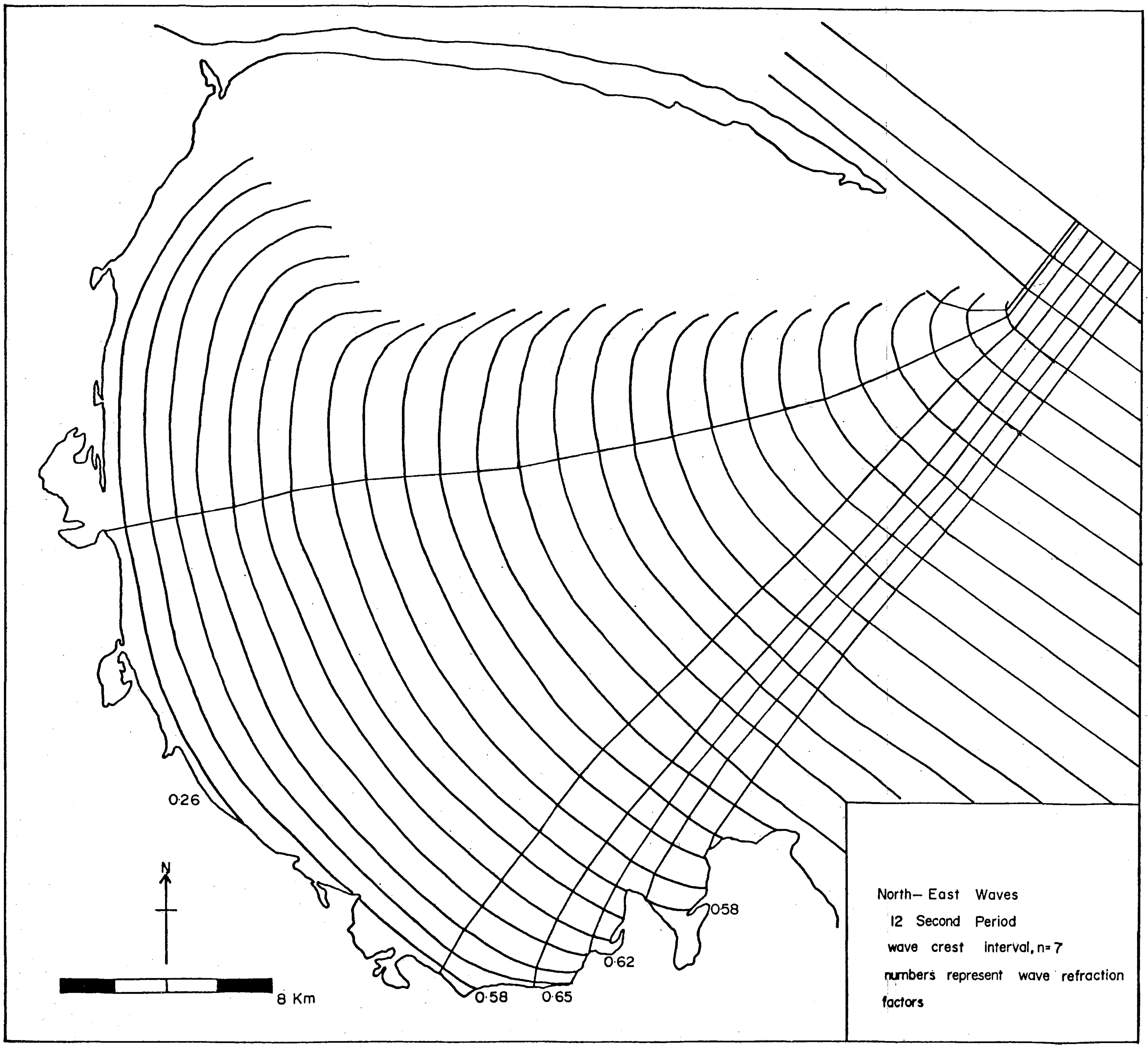


Fig. 3. 5 - Wave refraction for North-East waves of 12 second period.

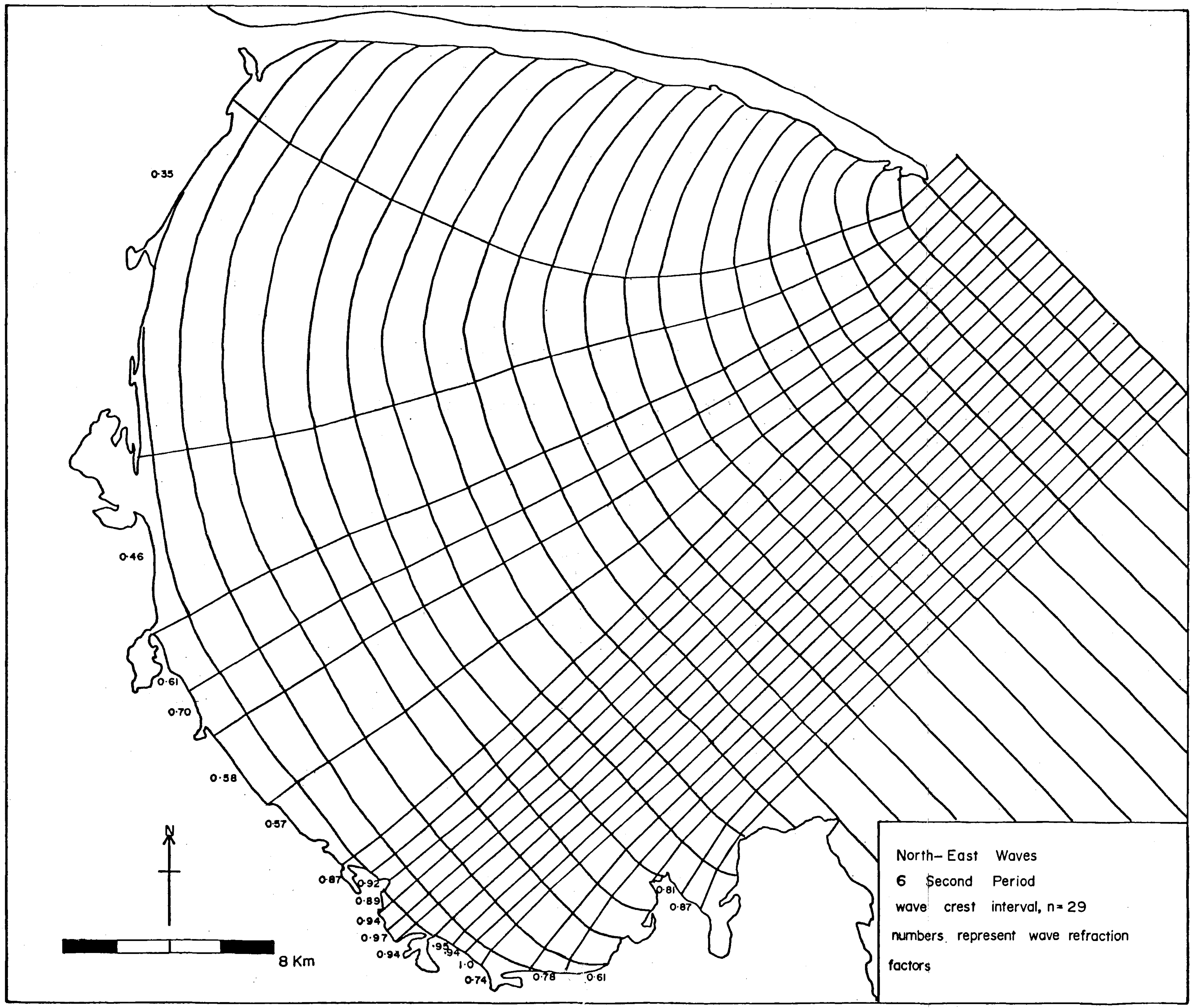


Fig. 3.6 - Wave refraction for North-East waves of 6 second period.

Analysis of the wave refraction diagrams and calculation of the wave refraction factors for the various wave environments (Figs. 3.4, 3.5 and 3.6) reveals a spatial variation in wave energy that is important in terms of the future discussion on beach dynamics and coastal compartments.

The northern part of Golden Bay is generally influenced by lower energy waves than other areas of Golden Bay. The approaching waves are strongly refracted, especially the north-east 12 second waves that are open-ocean storm waves, which are diffracted in the lee of Farewell Spit. The southern areas of Golden Bay are subject to higher concentrations of wave energy, especially from north-east 6 second period waves and from short-steep locally generated north-west waves. The north-west 6 second period wave is inhibited in its growth by the relatively shallow depth and so the true significance of the locally generated north-west wave is not revealed by the 6 second period wave.

As the northern part of Golden Bay is generally subject to lower wave energies than the southern areas an appreciable rise in the sea level and wave energy, due to storm surges, may cause greater relative changes in beach morphology than would occur on the more exposed southern coastline.

This discussion on spatial variations in beach morphodynamics, as a result of variations in wave energies, will be further developed in Chapter Four.

3.7.2 Spatial Variation in Longshore Sediment Transfers.

This discussion will primarily explain the patterns and rates of longshore sediment transport as inferred from the refraction diagrams and calculated using the energy flux variations around Golden Bay.

As can be seen from Figures 3.7, 3.8 and 3.9, the Golden Bay coastline may be divided into three sectors in which certain longshore sediment rates and directions are proposed for the significant wave environments.

The gross sediment transport rate for the northern sector is approximately $2.7 \times 10^5 m^3 yr^{-1}$ which is all moved in a northerly direction. About 45% of this gross rate is moved by waves from the north-west sector.

Slightly less sediment is transported in the central sector, $2.4 \times 10^5 m^3 yr^{-1}$, as the waves approach the shore in a parallel fashion and an oblique wave approach is desirable for significant longshore transport. Approximately 75% of this gross rate is transported in a net northerly direction, predominantly by north-east 6 second period waves.

The gross sediment movement in the southern sector is in the order of $8.0 \times 10^5 m^3 yr^{-1}$. Approximately 60% of this gross rate is moved in a net westerly direction, predominantly by north-east 6 second period waves.

The total gross sediment rate for the whole Bay is in the order of $1.3 \times 10^6 m^3 yr^{-1}$. Net movement in a north-westerly direction accounts for approximately 70% of this gross rate. The predominant sediment transporting regime is the north-east wave environment.

These longshore sediment transport directions and rates are purely theoretical and offer only an indication of potential longshore sediment movement. Significantly different rates and directions may be evident around Golden Bay as a result of different sediment supply sources and net local variations in direction of sediment movement. For example, the southern sector may have less gross sediment

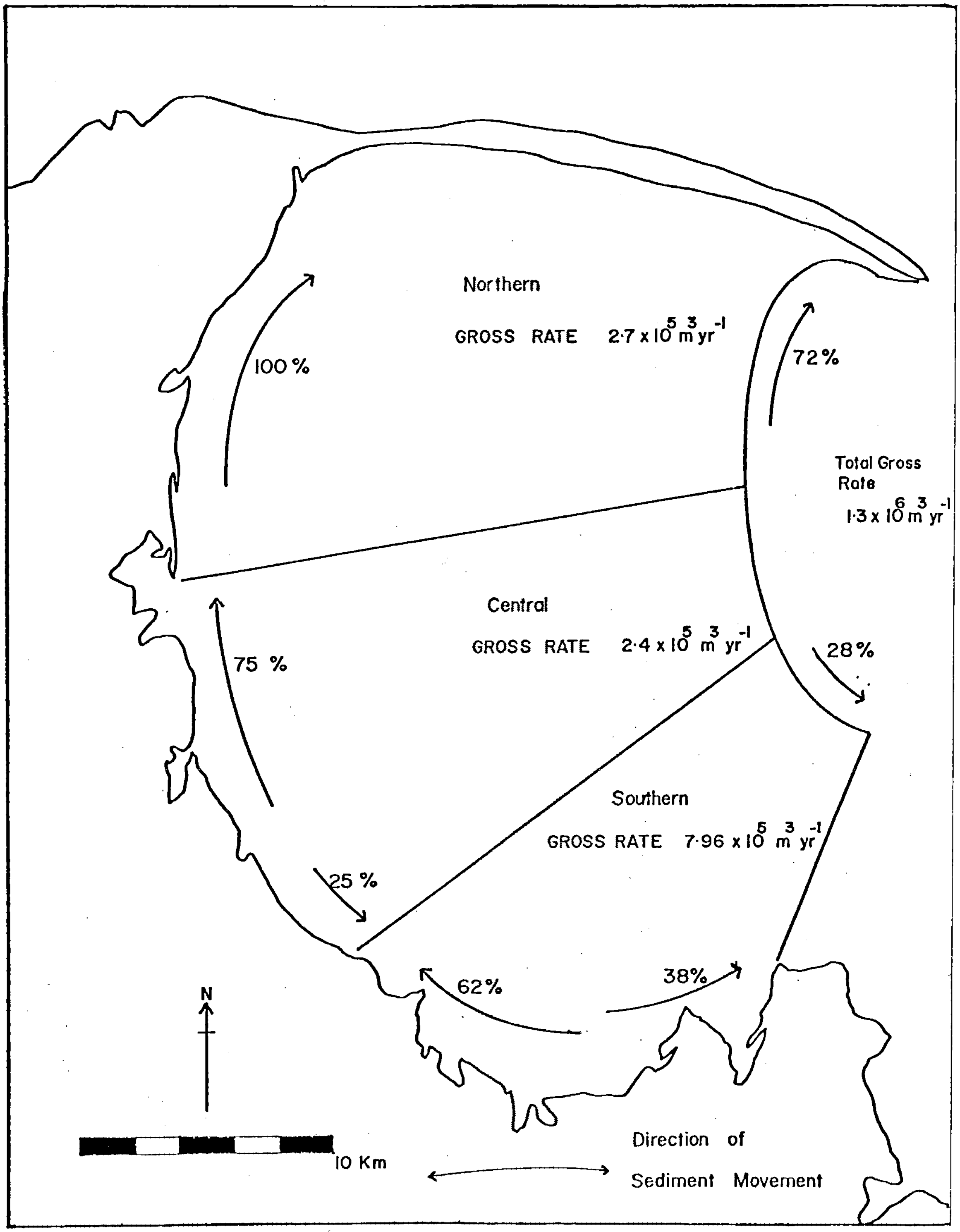


Fig. 3.7 - Longshore sediment zones, showing net rates of movement for each zone.

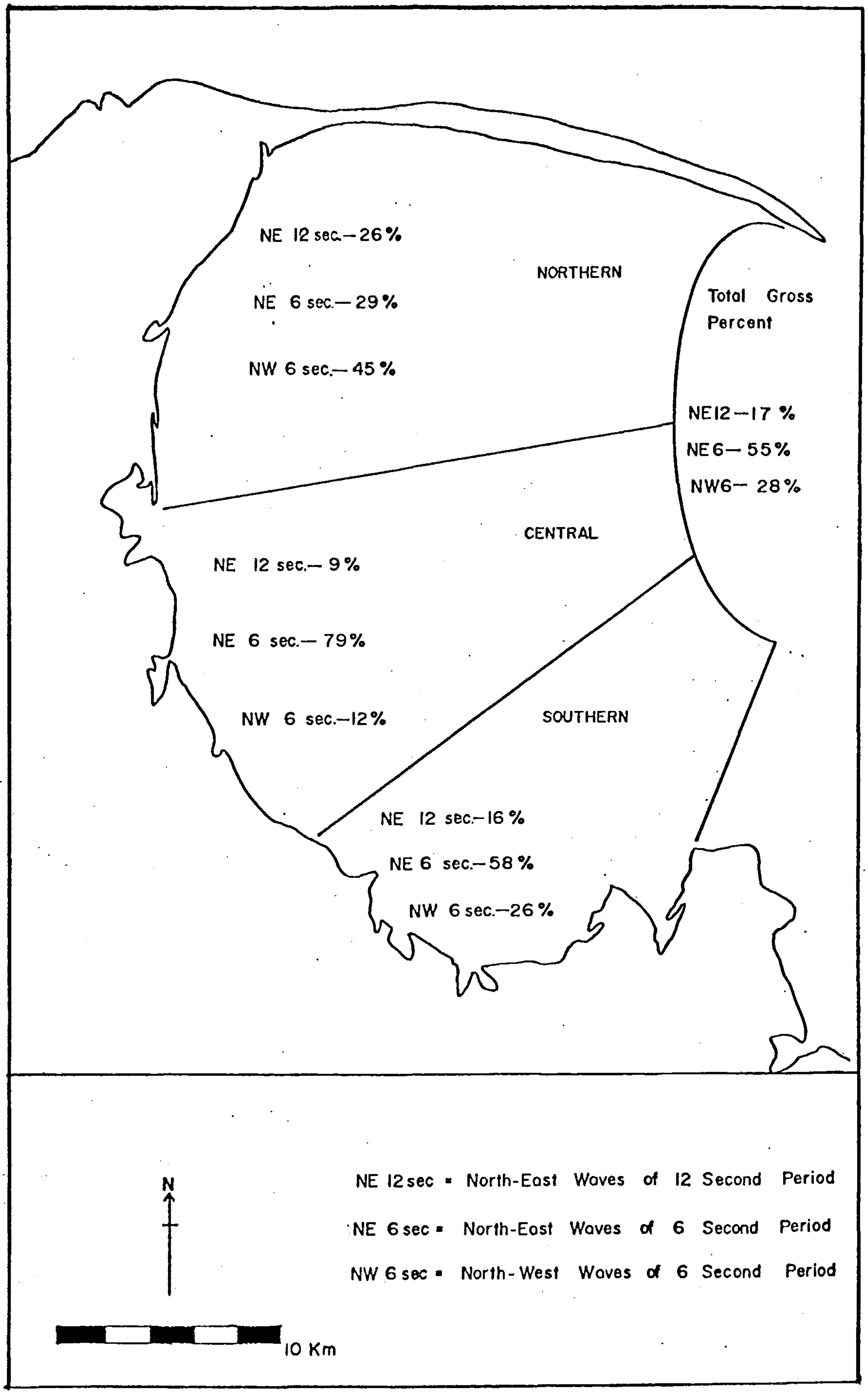


Fig. 3.8 - Percent of gross rate moved by significant wave regimes.

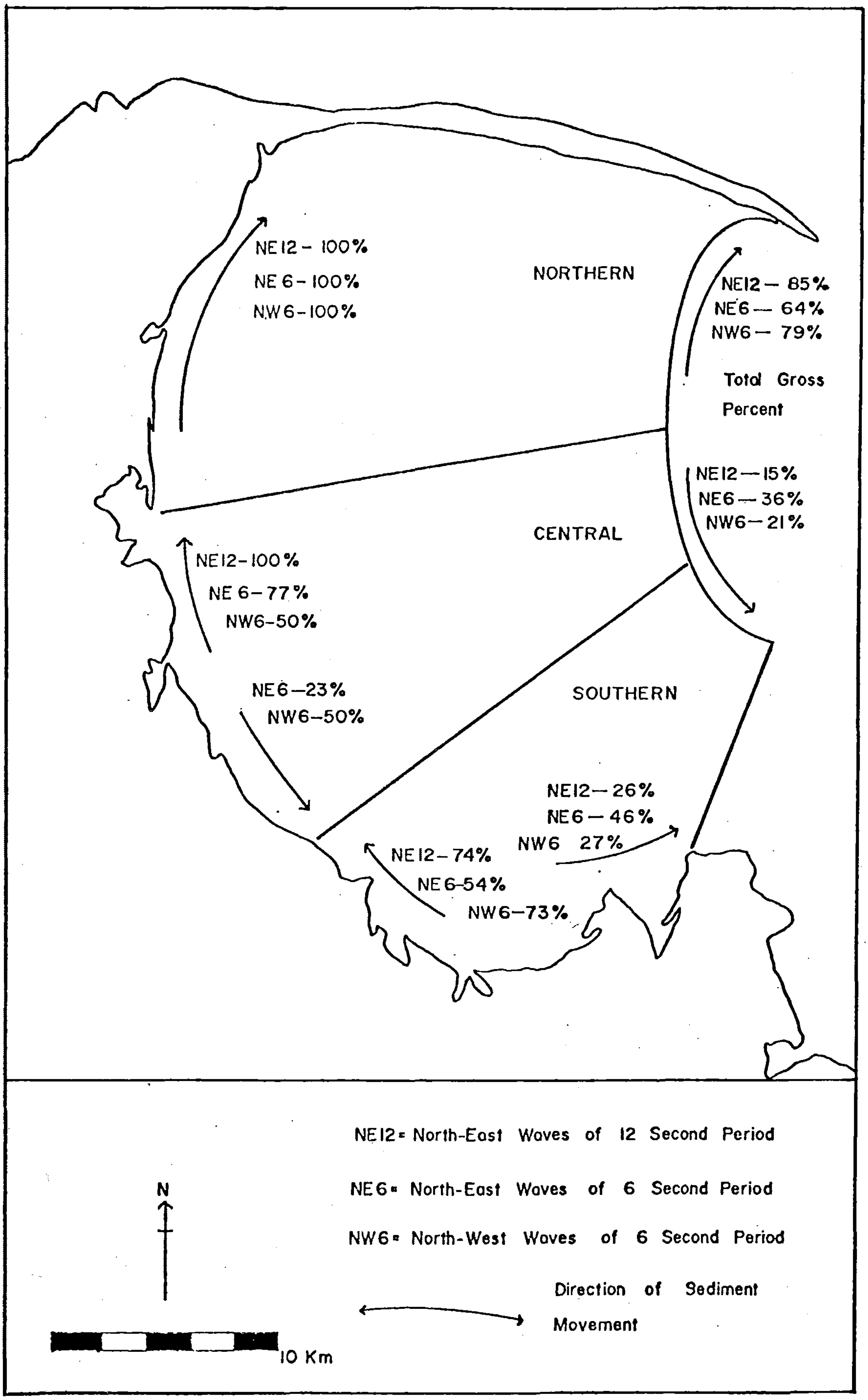


Fig. 3.9 - Percent of gross zone rates moved by significant wave regimes in specific direction.

movement as the sediment supply is less than for the northern and central sectors where the rivers supply abundant sediment to the coastal system. The analysis does show that the potential for significant longshore sediment transport is greater in the southern sector. The directions of longshore movement, shown by Figure 3.7, are more significant than the theoretical rates and except for local net variations in drift direction the directions shown are supported by sedimentary and morphologic evidence discussed in later chapters.

3.8 SUMMARY

Based on the interpretation of the available wind and wave data and the construction of wave refraction diagrams for the significant wave conditions, the physical process environment of Golden Bay may be summarised thus:

The dominant feature to emerge from the wind and wave data is the large proportion of the time for which winds blow from a direction and at a speed that results in very calm sea conditions. Rough sea conditions are the result of locally generated high velocity north-west winds and open-ocean swell and storm waves, generated by weather systems outside the study area, that may filter into Golden Bay.

A seasonal pattern emerges from the analysis of this data. The spring-summer months are periods of rougher sea conditions and so periods of beach erosion may be more common during these months. In contrast, the calmer wind and wave conditions during the autumn-winter period are likely to result in periods of beach accretion. This is a significant proposal as it is contrary to the usual seasonal pattern identified in the literature.

Spatial variations exist around Golden Bay for wave energies and for patterns and rates of longshore sediment movement.

The northern part of Golden Bay is exposed to generally lower wave energies that result from extreme refraction and diffraction of the approaching waves. The southern parts of Golden Bay receive a higher concentration of wave energy as the waves are less refracted and so reach the shore with less divergence.

The direction of sediment movement in the northern part of Golden Bay is primarily in a northerly direction and north-west waves are responsible for about 45% of this northerly movement. As waves approach the shore in a parallel fashion in the central regions the amount of sediment movement is less. Approximately 75% of the sediment is moved in a northerly direction predominantly by north-east 6 second period waves. The southern parts of Golden Bay have the largest amounts of potential longshore sediment movement predominantly moved in a westerly direction by north-east waves.

These rates are purely theoretical and offer only an indication of potential longshore sediment movement. Major influencing factors such as sediment supply sources may drastically alter these proposed rates. Of greater significance is the proposed longshore sediment transport directions for the various sectors and for Golden Bay as a whole. The predominant net westerly longshore drift is reinforced by a westerly circulation pattern previously discussed in Chapter Two. These proposals, as to net sediment movement, will be of consequence in the following chapters.

CHAPTER FOUR

COASTAL SEDIMENTS AND MORPHOLOGY

1. INTRODUCTION

Sediment characteristics are influenced by original source characteristics and by subsequent mixing, sorting and winnowing in the littoral environment. Therefore the study of sediment characteristics and their spatial patterns can reveal much about the nature and distribution of active sediment sources and dispersal patterns in the marine environment. If the coastal depositional system is viewed as involving changes in the sediment flux in association with changing energy regimes, then the dynamic characteristics of the system can be understood in a temporal sense.

Many studies have shown how particle size influences the form of beaches in conjunction with other elements of the beach system. It is well known that a relationship exists between the foreshore slope of a beach and the average size grade of the foreshore sediment, increasing slope angles being associated with increasing particle dimensions. The size of the material exerts a primary control on foreshore slope which is then subject to secondary factors such as degree of exposure to wave energies.

Thus this investigation into the beach sediments and morphology of Golden Bay has a twofold purpose. First, to discuss the spatial variation of the beach sediment characteristics around Golden Bay and, secondly to discuss the spatial and temporal variation of the beach morphology with respect to the factors which control the beach form, that is beach material and energy regimes.

4.2 SEDIMENT VARIATION AROUND GOLDEN BAY

4.2.1 Previous Research

The only previous investigation into Golden Bay's beach sediments was carried out by Berqurst et al. in 1975. In this study some fifty samples were collected from dunes, beach faces, intertidal sand flats and estuaries. They concluded that the sediment samples were uniform in character, being medium to fine sands that were very well to well sorted (Berqurst et al., 1975, p. 8). The only significantly different samples were those from beaches in which the sediment source is the local granite cliffs. The samples of these beaches were of a very coarse nature and less well sorted.

The offshore sediments of the Golden Bay area were examined by van der Linden (1969) who found that the materials in the Farewell Spit area are fine to medium sands which have blown across the Spit and deposited on the intertidal flats. Sediments further south in Golden Bay were thought to be supplied by the Aorere and Takaka Rivers. These sediments generally have a higher proportion of mud and are less well sorted. It was also found that they contained minerals which indicate derivation from an igneous and metamorphic terrain, such as that which occurs inland of Golden Bay.

4.2.2 Sample Collection and Analysis.

For the present study 25 sample sites were chosen, 23 of these being at locations where beach profiles were being surveyed. For all but two of these sites three sediment samples were collected, one each at approximately high tide, mid tide and low water levels. At the remaining two sites only a high tide level sample was collected. Figure 4.1 and Table 4.1 show the location of the sites.

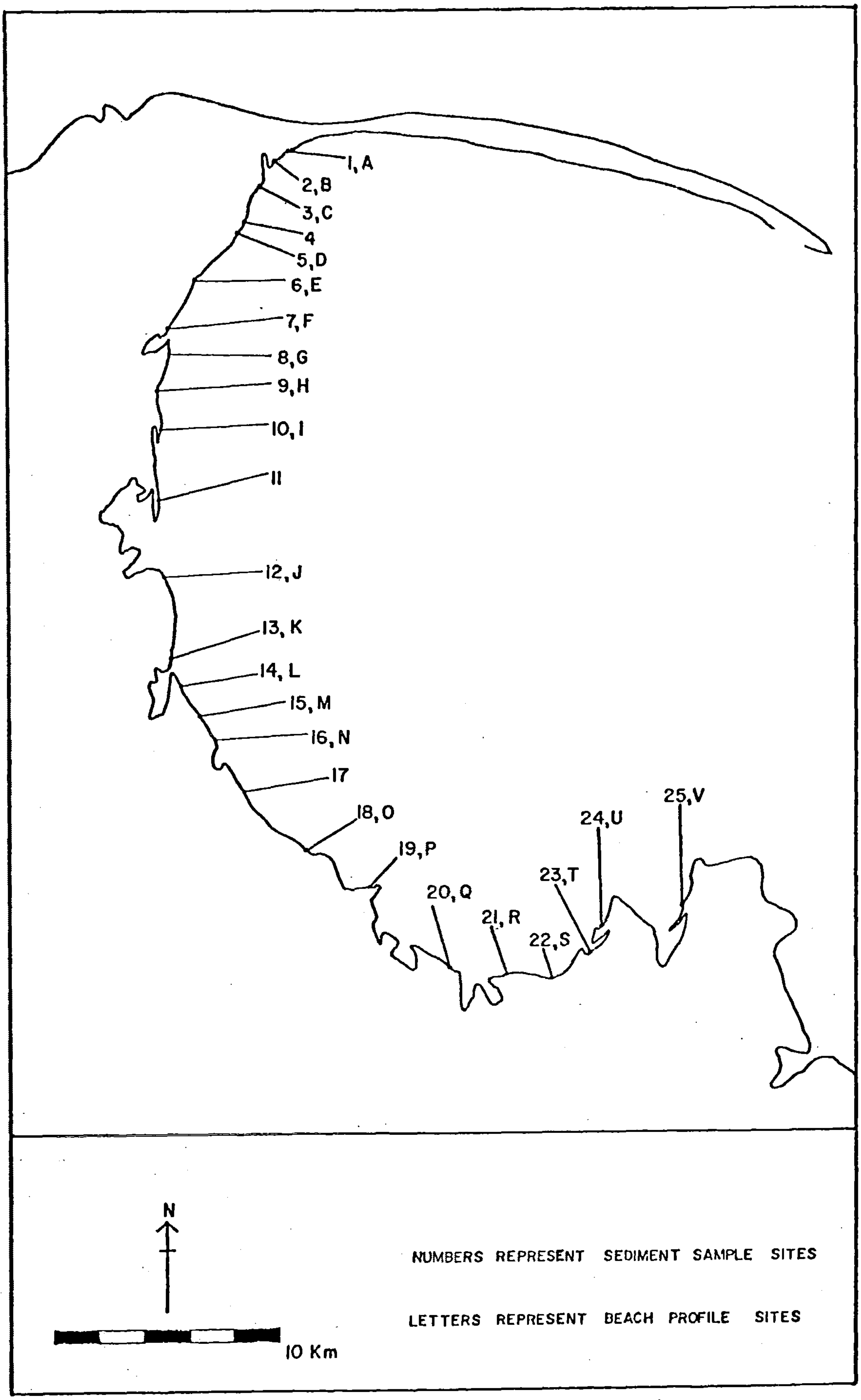


Fig. 4. 1 - Beach sediment sample and profile locations.

Table 4.1 - Summary of analysis of beach sediment samples. Numbers represent sediment sample sites. Letters represent beach profile sites.

Site No.	Grid (1) location	Folk Parameters $M_2(\phi)$	$0_1(2)$	Percent $CaCo_3$	Type of Sample
1, A	S1, S3/155218	1.80	0.38	9.6	High Tide
	"	2.18	0.30		Mid Tide
	"	2.50	0.52		Low Tide
2, B	S1, S3/148211	0.67	1.14	47.3	High Tide
	"	1.35	1.11		Mid Tide
	"	2.60	0.73		Low Tide
3, C	S1, S3/142209	1.35	0.39	2.2	High Tide
	"	0.73	1.70		Mid Tide
	"	2.76	0.49		Low Tide
4	S1, S3/133185	-0.73	1.86	1.4	High Tide
	"	1.55	0.56		Mid Tide
	"	2.11	0.27		Low Tide
5, D	S1, S3/129183	-5.63	0.64		High Tide
	"	2.15	0.60		Mid Tide
	"	2.10	0.34		Low Tide
6, E	S1, S3/122173	0.61	1.27		High Tide
	"	1.60	0.56		Mid Tide
	"	1.78	0.36		Low Tide
7, F	S1, S3/106152	2.35	0.41	2.2	High Tide
	"	1.98	0.53		Mid Tide
	"	1.63	0.97		Low Tide
8, G	S1, S3/102128	1.78	0.45		High Tide
	"	2.13	0.42		Mid Tide
	"	2.41	0.34		Low Tide
9, H	S1, S3/097112	1.35	0.53		High Tide
	"	1.23	0.47		Mid Tide
	"	1.76	0.63		Low Tide
10, I	S1/S3/094097	1.91	0.54		High Tide
	"	1.01	0.41		Mid Tide
	"	1.30	0.47		Low Tide
11,	S1, S3/093072	1.30	0.56		High Tide
12, J	S1, S3/097015	2.20	0.41	4.5	High Tide
	"	2.83	0.40		Mid Tide
	"	2.30	0.72		Low Tide
13, K	S1, S3/098984	1.53	0.58	3.6	High Tide
	"	0.66	1.79		Mid Tide
	"	0.53	1.11		Low Tide
14, L	S1, S3/102973	2.41	0.37		High Tide
	"	2.16	0.53		Mid Tide
	"	2.11	0.66		Low Tide
15, M	S1, S3/112957	1.41	0.49	1.0	High Tide
	"	1.86	0.35		Mid Tide
	"	1.40	0.78		Low Tide
16, N	S1, S3/118943	1.56	0.36	3.3	High Tide
	"	1.60	0.58		Mid Tide
	"	1.40	0.71		Low Tide
17	S1, S3/130925	2.10	0.31		High Tide
18, O	S8/161894	2.38	0.34	4.5	High Tide
	"	2.06	0.43		Mid Tide
	"	2.13	0.55		Low Tide
19, P	S8/189876	2 36	0.43	1.8	High Tide
	"	1.83	0.58		Mid Tide
	"	2.26	0.28		Low Tide
20, Q	S8/232842	1.66	0.85	3.4	High Tide
	"	2.43	0.62		Mid Tide
	"	2.41	0.54		Low Tide
21, R	S8/255837	2.40	0.39	2.0	High Tide
	"	2.11	0.76		Mid Tide
	"	2.93	0.50		Low Tide
22, S	S8/277836	2.38	0.31		High Tide
	"	2.60	0.25		Mid Tide
	"	2.80	0.20		Low Tide
23, T	S8/298848	-0.10	0.71		High Tide
	"	1.31	0.58		Mid Tide
	"	1.46	0.34		Low Tide
24, U	S8/306864	-0.15	0.66		High Tide
	"	-0.56	0.68		Mid Tide
	"	-0.81	0.68		Low Tide
25, V	S8/343872	-0.30	1.41		High Tide
	"	2.26	0.38		Mid Tide
	"	2.08	0.35		Low Tide

Note: (1) Grid reference to NZMSI Maps Sheet S1 and S3 (1974) and S8 (1974).

(2) See Appendix Two for verbal classification.

While the number of sample sites is small, they are considered to be representative of the major coastal environments around Golden Bay.

The initial laboratory treatment of each sample consisted of washing with fresh water in a five litre beaker. This was done to remove any salt and plant detritus present. It also allowed for an assessment of the amount of fines (silt and clays) and organic matter. In all cases but one fines formed an insignificant amount of the total sample, less that 1% of the total sample weight. The low tide sample at site A contained 2% organic matter of total sample weight. After washing the samples were dried.

The beach face at site **5** consisted predominantly of relict gravel deposits and so field sieves were used in the initial sieving of the high tide sample. All other samples were split, in the laboratory, into smaller subsamples. A 100 gm subsample was then dry sieved at approximately 0.25 ∅ intervals.

Approximately half of the beach sediment samples contained amounts of biogenic calcium carbonate material. Significant amounts of shell material will change the behaviour of the beach sediments under wave action and this may be reflected in the beach morphology. Accordingly it was necessary to determine the shell content.

Two procedures were followed in ascertaining the shell content of a high tide sediment sample. First of all the larger shell fragments were separated out into the coarser sieves during the sieving process. These fragments were collected and weighed. Secondly the shell content of the finer fraction of the sieved sample was subsplit into a 1 gm sample. This smaller sample was then analysed for shell content by the weight loss after acid digestion method (Gillie, 1979, pp 105-107).

4.2.3 Sediment Size Characteristics

The results from the analysis of beach sediment samples, specifically high tide samples, are presented in Table 4.1, Figure 4.2 and Table 4.2 and Figure 4.3. All particle sizes have been expressed in the phi (Ø) scale, which is $-\log_2(D)$ of the particle diameter in millimetres (Appendex One). For each sample the parameters of Graphic Mean, Inclusive Graphic Standard Deviation, Skewness and Kurtosis have been determined according to the procedures outlined in Folk (1974) and in Appendix Two. The Graphic Mean and Standard Deviation measures for the beach samples are summarised in Table 4.1.

The spatial variation in the mean grain size for the beachface samples, as shown by Figure 4.2, reflects the importance of the various sediment supply sources in Golden Bay. The majority of the samples are medium to fine grained sands (Figure 4.3) which characterise beaches located close to river and inlet mouths and which are the predominant suppliers of sediment in Golden Bay. The very coarse to cobble sized beach face sediments, as found at sites 4 and 5 (Plate 4.1), occur where relict gravel terraces are exposed at the coast and boulder/cobble/pebble concentrations accumulate on the beach face. The very coarse beach face sediments at sites 23, 24 and 25 are derived from local granite cliffs. Cliffs act as sediment sources only for beaches located immediately adjacent to the cliff area. Overall this source provides sediment for only a few beaches.

The intertidal sediment samples, mid tide and low tide water levels, generally show a decrease in mean grain size from mid tide

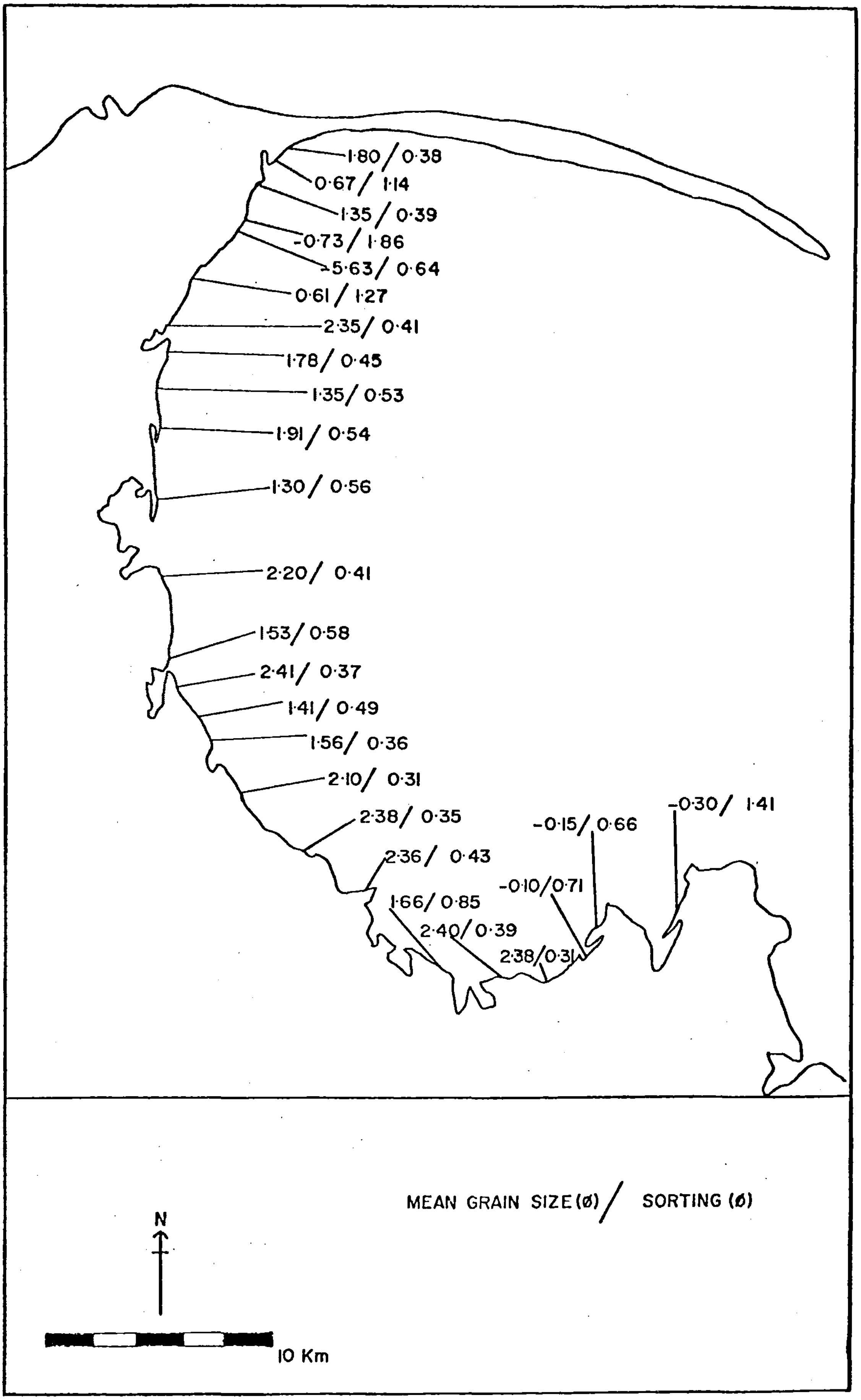


Fig. 4.2 - Spatial variation in mean grain size and sorting for high tide beach samples.

Table 4.2 - Size characteristics of high tide beach samples.
(Folk parameters in ∅ units)

Sample Site Number	Size Fraction (%)		
	>-1 ∅	-1 to 1 ∅	<1.0 ∅
1	0	2	98
2	6	59	35
3	0	17	83
4	30	61	9
5	100	0	0
6	13	31	56
7	0	1.5	98.5
8	0	3	97
9	0	25	75
10	0	1	99
11	0	46	54
12	0	0	100
13	0	17	83
14	0	0	100
15	0	19	81
16	0	4	96
17	0	0	100
18	0	0	100
19	0	0	100
20	0	24	76
21	0	0	100
22	0	0	100
23	6	84	10
24	14	84	2
25	40	40	20

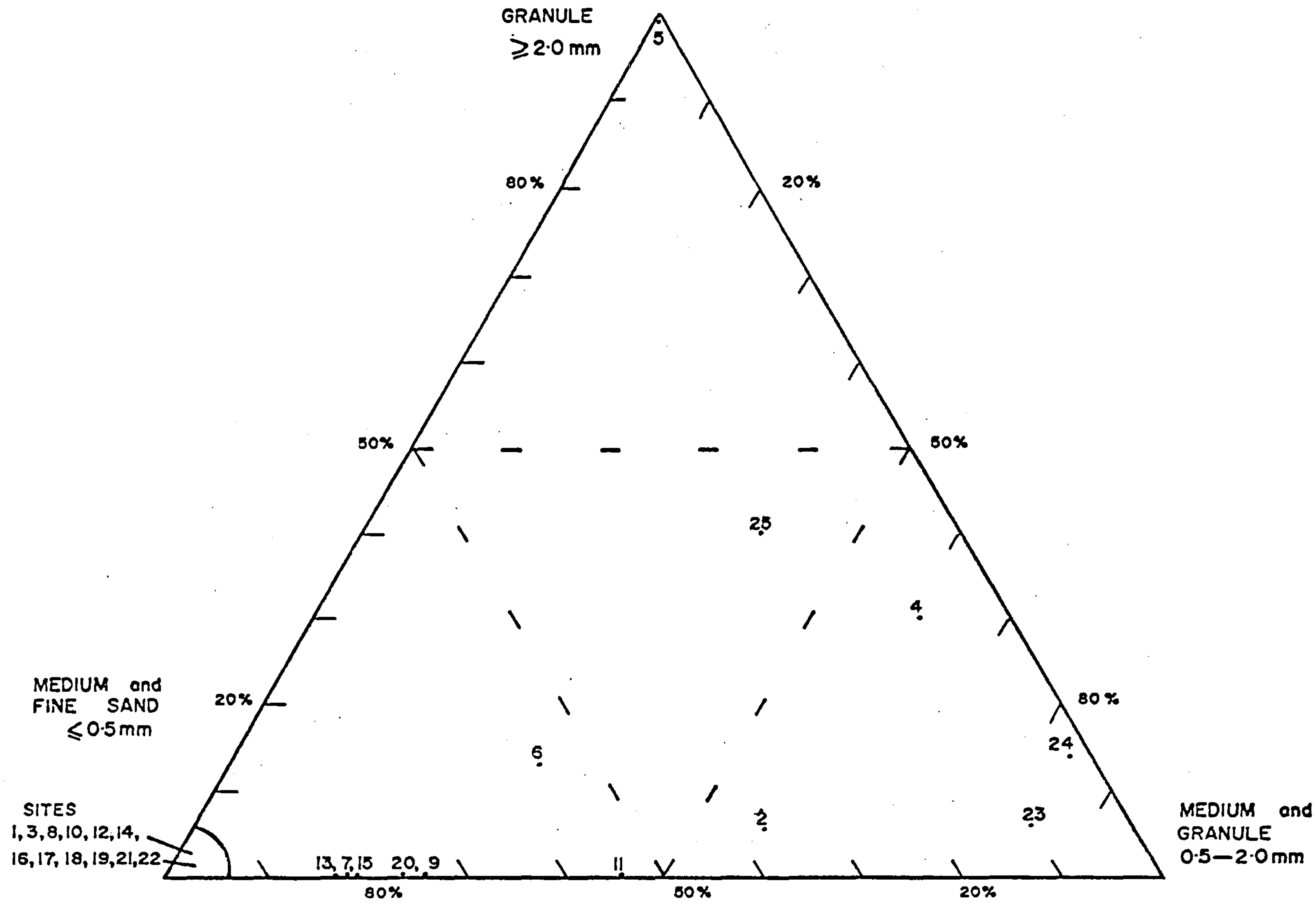


Fig. 4.3 - Size sorting characteristics of 25 beach sediment samples.

to the low tide water level. There are, however, some sites where the tidal flat sample is coarser than the beach face sample, such as sites 7 and 13. These coarser intertidal sediments reflect the mixing of rock fragments with the sandy sediment on the tidal flat. Rock fragments are common where relict gravel deposits are an inherited feature of the coastline and fragments are reworked off the beach area and on to the tidal flat.

The content of shell material in the beach face sands varies from 1.0% at site 15 to approximately 47.0% at site 2. The spatial variation in shell content of the beach sediment relates to the location of the different benthic communities and the ability of the wave processes to bring the shell material onshore. Berqurst et al. (1975) identified the locations of these benthic communities. It was shown that the greatest offshore concentrations of scallops (Pecten novaezelandiae), mussels (Perna canaliculus) and oysters (ostrea lutaria) occur in the central and northern areas of Golden Bay (Berqurst et al., 1975, pp 22-25). The beaches in the central and northern part of Golden Bay contain a correspondingly large amount of the above shell communities and many types of mulluscs. As stated shell material comprises a significant part of the beach sediment at site 2 (Plate 4.2) and has an affect on the beach sediment texture (for example, sorting) and also on the beach morphology. Certain shell communities live in estuarine environments, which would account for larger accumulations of shell types on beaches near inlet openings as at sites 16, 20 and 21.

A scatter plot of standard deviation-sorting against mean size of beach face sediment (Figure 4.4) shows a portion of the sinusoidal trend which has been recognised by numerous workers (for example, Folk, 1974 and discussed in relation to New Zealand coastal areas by Andrews and van der Lingen, 1969 and McLean and Kirk, 1969).

Plate 4. 1 - Boulder/cobble/pebble accumulations on beach at site 5, D.

Plate 4. 2 - Shell accumulations on beach at site 2, B.

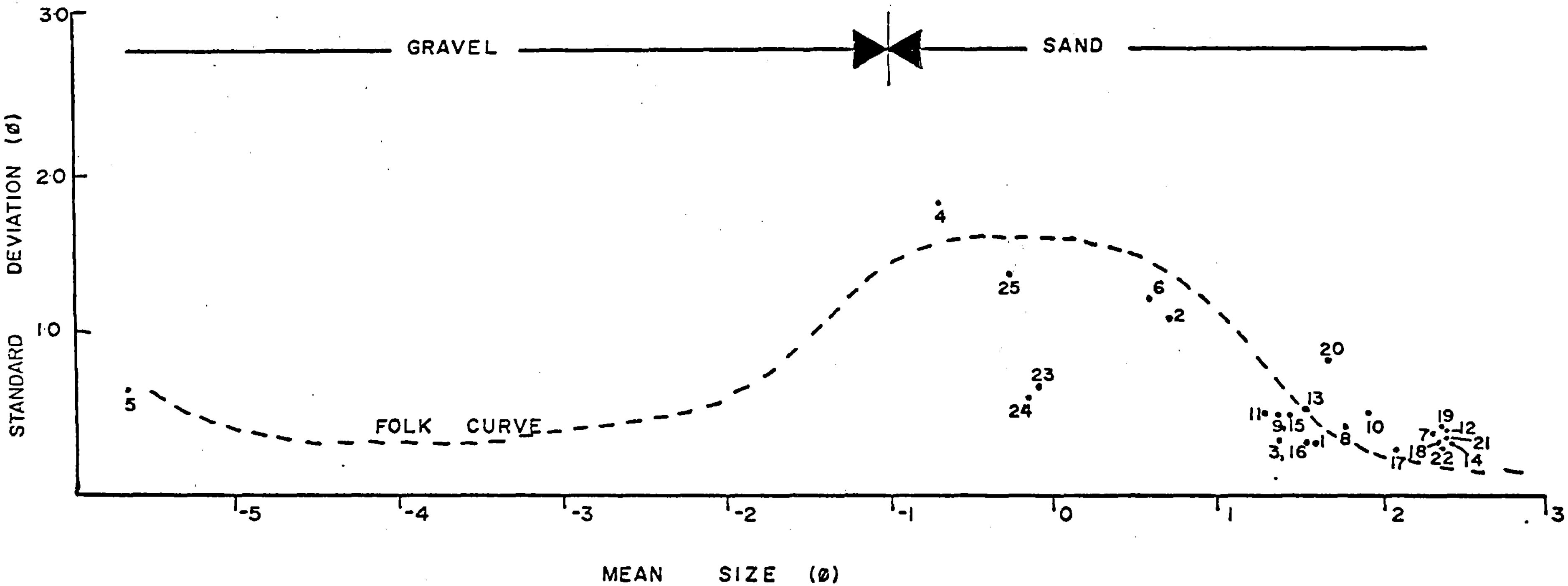


Fig. 4.4 - Relationship of standard deviation (sorting) to mean grain size for high tide beach samples.

From the plot it can be seen that the best sorting occurs in the medium to fine sands and to a lesser extent in the gravel deposits. The poorest sorting is associated with beach face samples that are generally of a very coarse nature.

The trend in Figure 4.4 is a function of both source area characteristics and hydraulic factors as proposed by McLean and Kirk (1969). The moderately sorted pebble samples are derived from relict gravel deposits which have been exposed at the coastline and hence are already sorted to some extent before wave action affects them. The poorly sorted coarse to very coarse sands at sites 2, 4 and 6 occur primarily as a result of mixing of rock fragments and shell detritus with finer grained sand particles. The moderately sorted beach face sediments at sites 23 and 25 occur as a result of a wide range of sediment sizes being contributed to the littoral zone by active sediment sources, such as the granite cliffs. The influence of hydraulic processes on the variability of the sorting trend of beach sediments is illustrated by the variation in sorting between sites 23, 24 and 25. The beach sediment at site 25 is of a similar texture to that at sites 23 and 24, but the beach at site 25 is less exposed to wave energy and a less well sorted sediment results. Finally, the best sorted sediments are those where the beach sediment is lithologically homogeneous. Variations around the major trend, for the well sorted samples, may be explained by spatial variations in degree of exposure of the beaches to wave energy.

A distinct zonation of grain sizes across the beach face exists on the very coarse sand and gravel beaches. The wave energy and related swash processes will reorganise the beach deposits into shape and size zones, with the larger size deposits at the top of the beach and the smaller size material at the base of the beach face.

The beach sediments around Golden Bay display a spatially varying pattern which is primarily a result of different sediment sources and the extent to which that sediment is distributed along the coast by the beach processes, such as by longshore transport systems. It has been shown that variations in the degree of sorting of the beach sediment is a result of original source characteristics and of hydraulic sorting of the sediment within the littoral zone. These variations in beach characteristics result in areas of the Golden Bay coastline that display distinct beach characteristics that will influence the beach morphology in these areas or compartments.

4.3 BEACH MORPHOLOGY AND DYNAMICS

4.3.1 Introduction.

Beaches composed of different sediment types but exposed to similar marine processes will show variations in beach response. Therefore based on the spatial variation in beach sediments and wave processes previously discussed, it is likely that spatial variations in beach morphology will be present around Golden Bay. The beaches may also display a temporal variation in morphology as a result of variations in sediment flux and wave process elements.

Therefore the purposes of this section are first, to describe the characteristic beach morphology and spatial variations in it and, secondly to describe the dynamics of the beaches.

4.3.2 Selection of Beaches and Field Survey Methods.

To provide the required information, twenty-two beaches' cross-sections were profiled five times over a period of seven months (December 1978 to June 1979).

The locations of the surveyed beach profiles are shown in Figure 4.1 and in Table 4.1. These locations were selected for two reasons. First, the sites reflect the spatial variation of the beach morphology in Golden Bay and secondly, the beach sites were readily accessible on a coastline where many areas are inaccessible.

Bench marks were established in November 1978 by installing wooden stakes in the back beach area where storm erosion effects were unlikely to occur. Profiles were surveyed using a Quickset level and Stadia rod along survey lines normal to the shore. The initial survey was extended out to low water level but in subsequent surveys only the beach face and part of the tidal flat was surveyed.

4.3.3 Beach Morphology.

The typical profiles developed around the Golden Bay coastline are shown in Figure 4.5. A typical beach profile form for the Golden Bay may be summarised as follows.

A narrow beach is usually backed by a low dune cliff which is reached by wave action only during spring high tides and/or during storm surges. The beach face has a gradient of 2-7^{o} depending on the beach sediment and degree of exposure to waves. Seaward of the beach there is an abrupt change in slope to a low tide sand flat. The width of this intertidal sand flat varies from virtually nil at Tata Beach (site U, Figs 4.5 and 4.1) to several hundred metres at Pohara Beach (site S, Figs 4.5 and 4.1) and exceeds one thousand metres north of Pakawau (sites A, B, C, D, E, F, Figs 4.5 and 4.1).

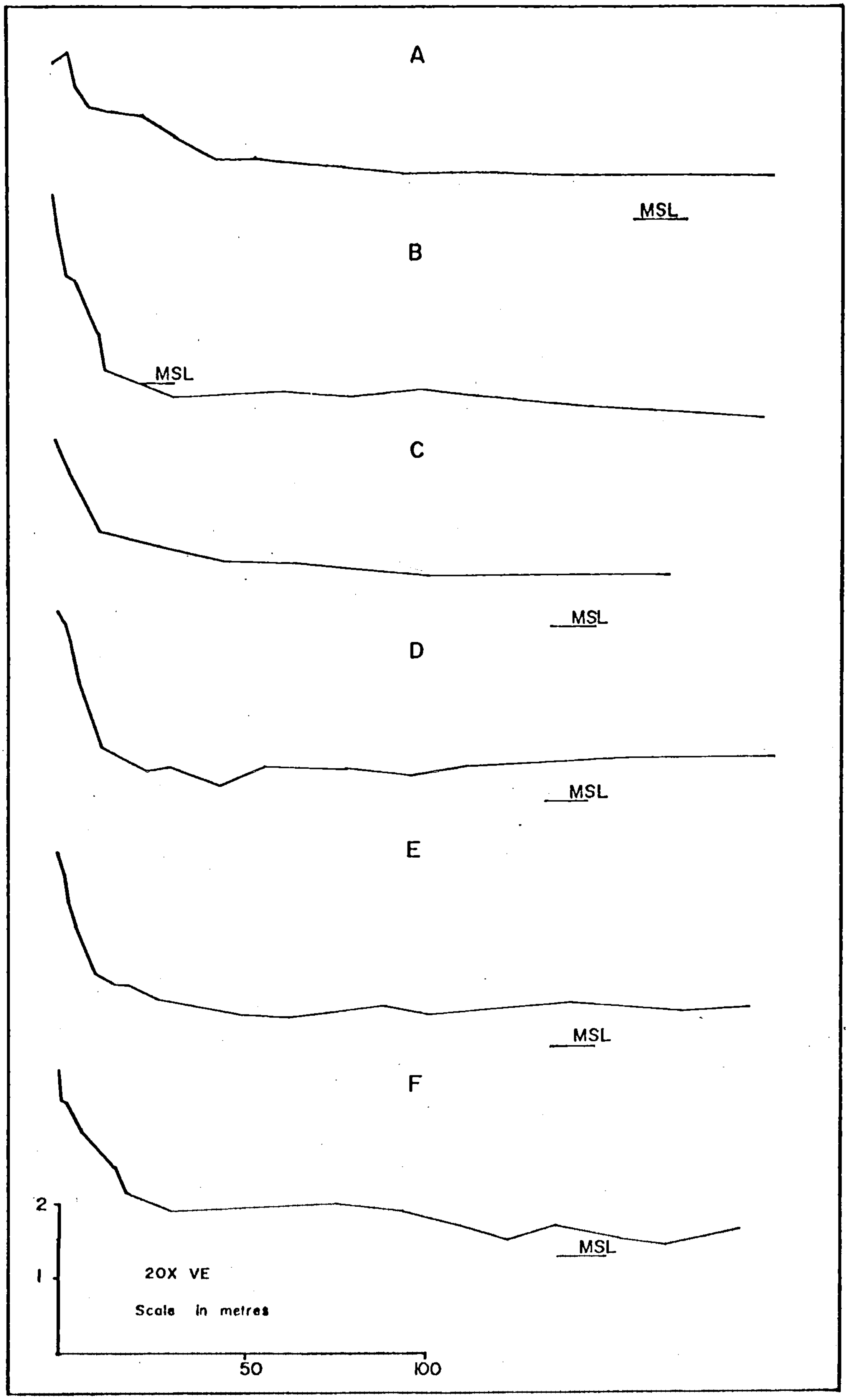


Fig. 4. 5 - Beach profile at locations as in Fig. 4. 1.

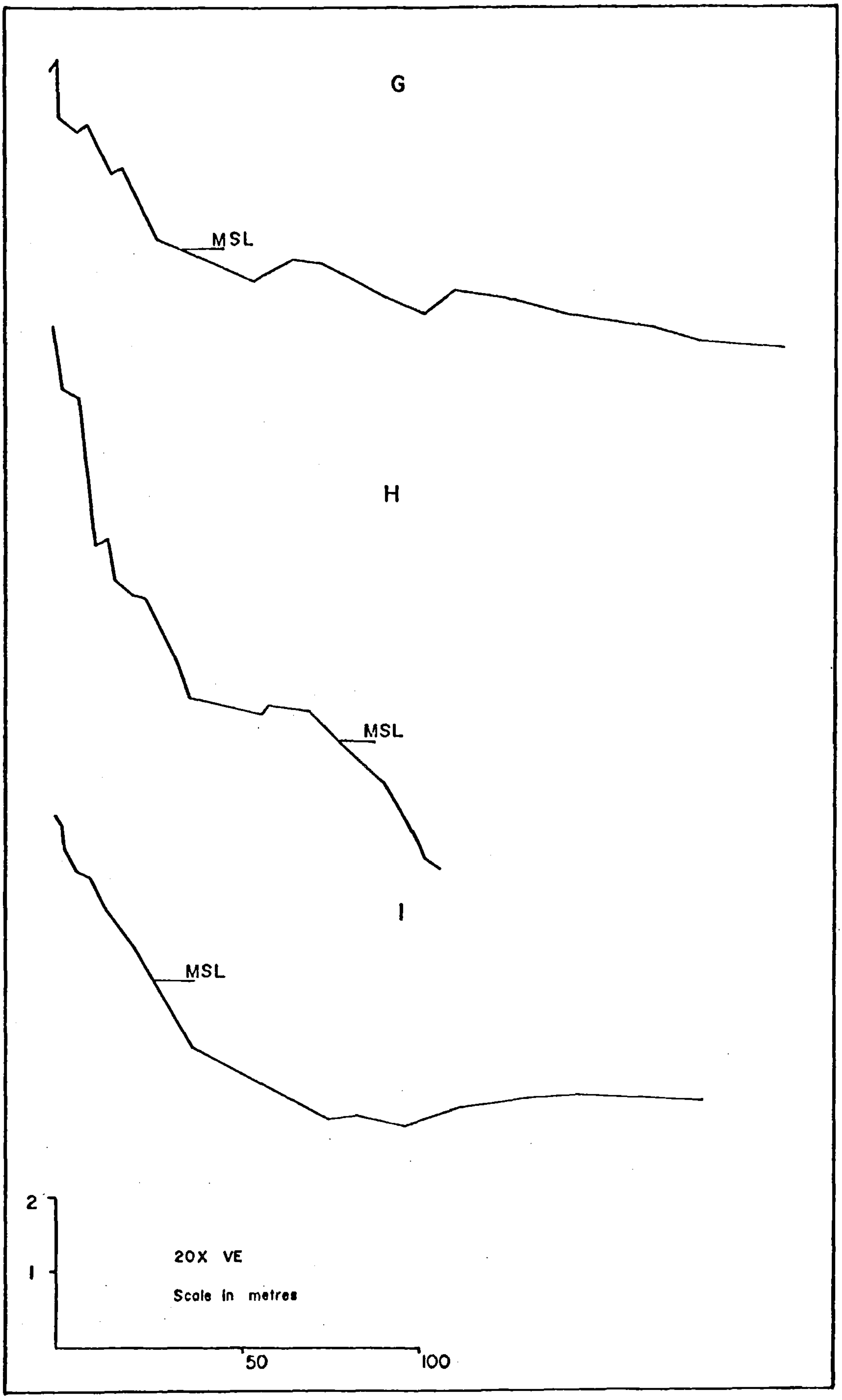
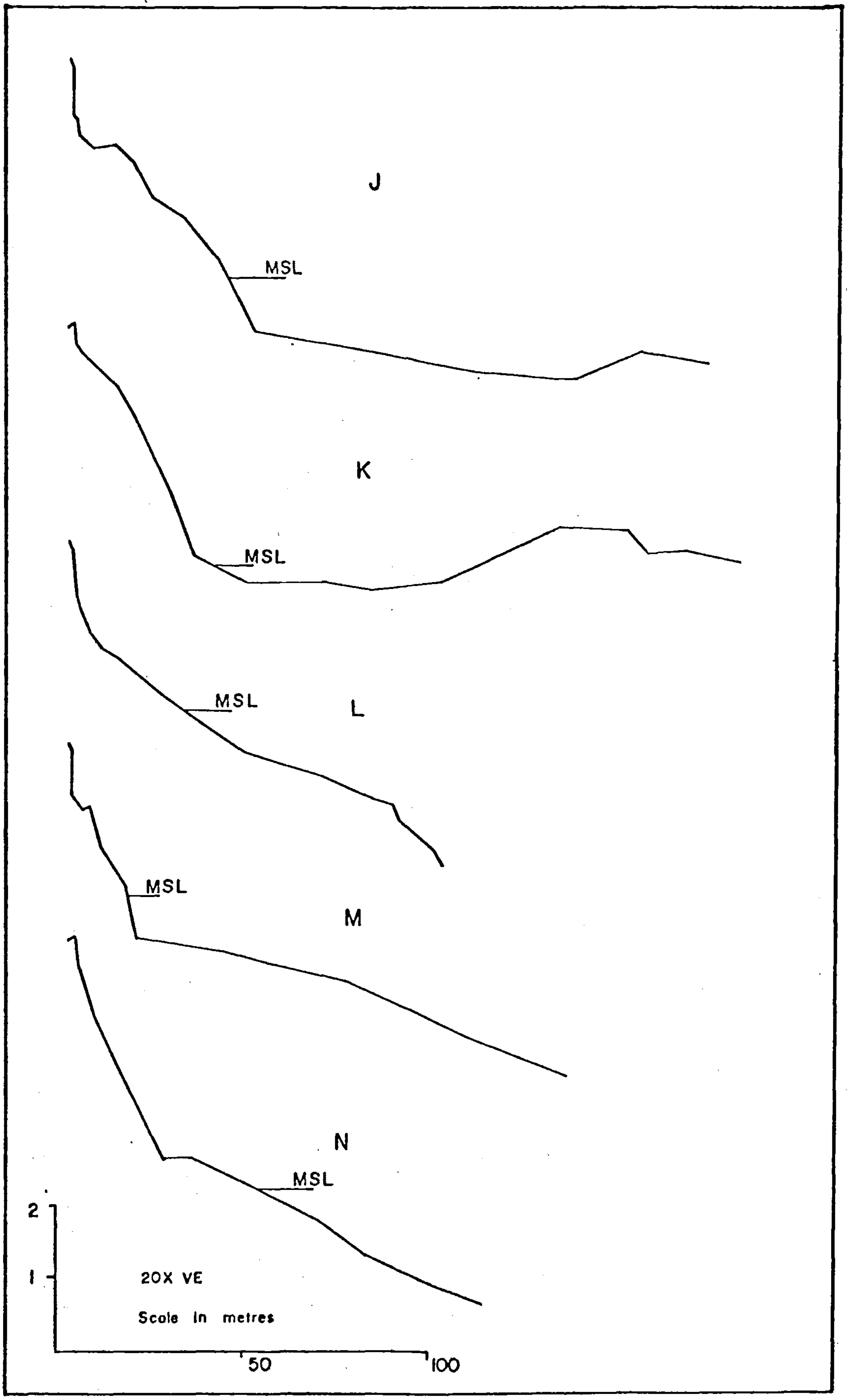


Fig. 4. 5 (Continued)



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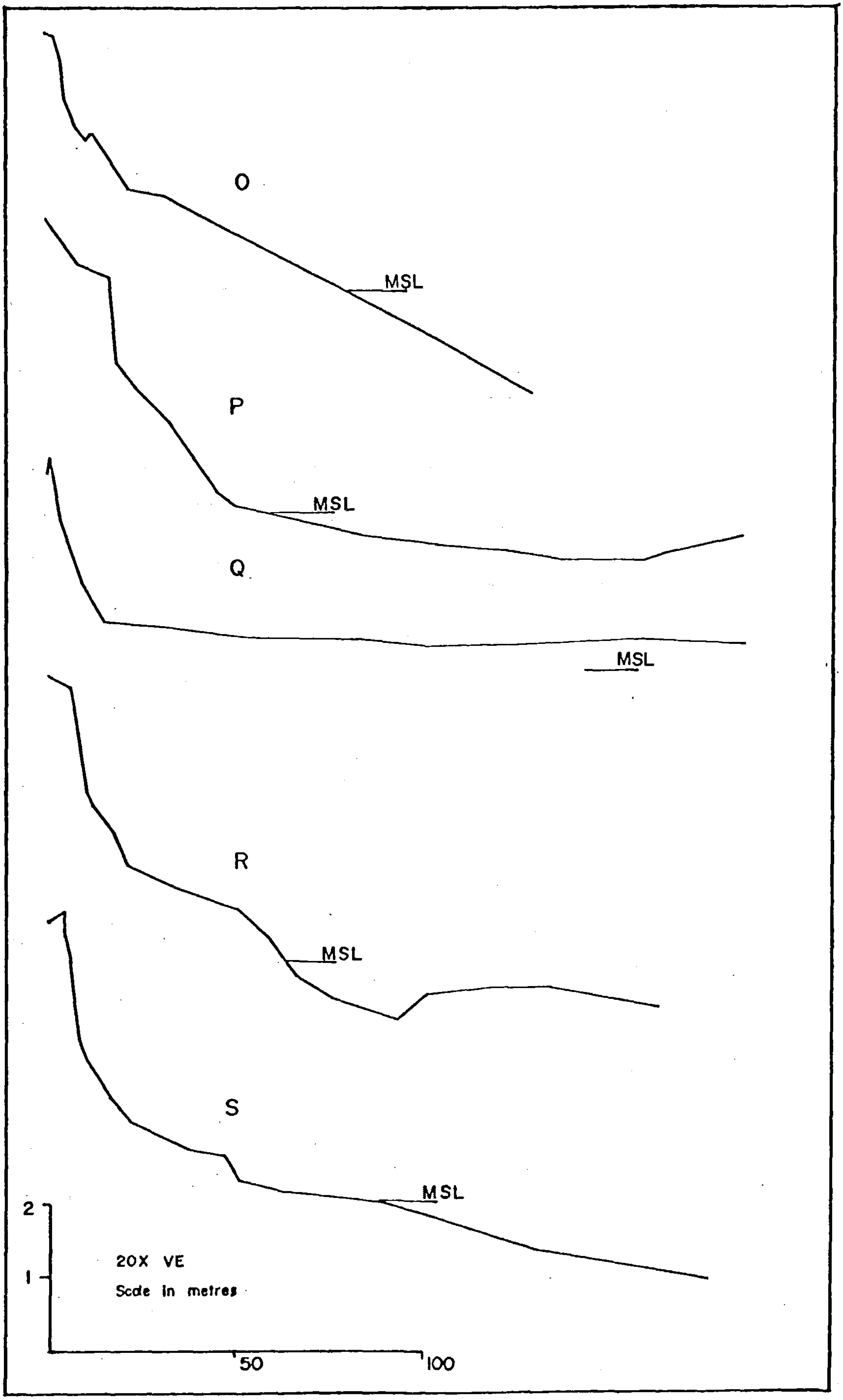

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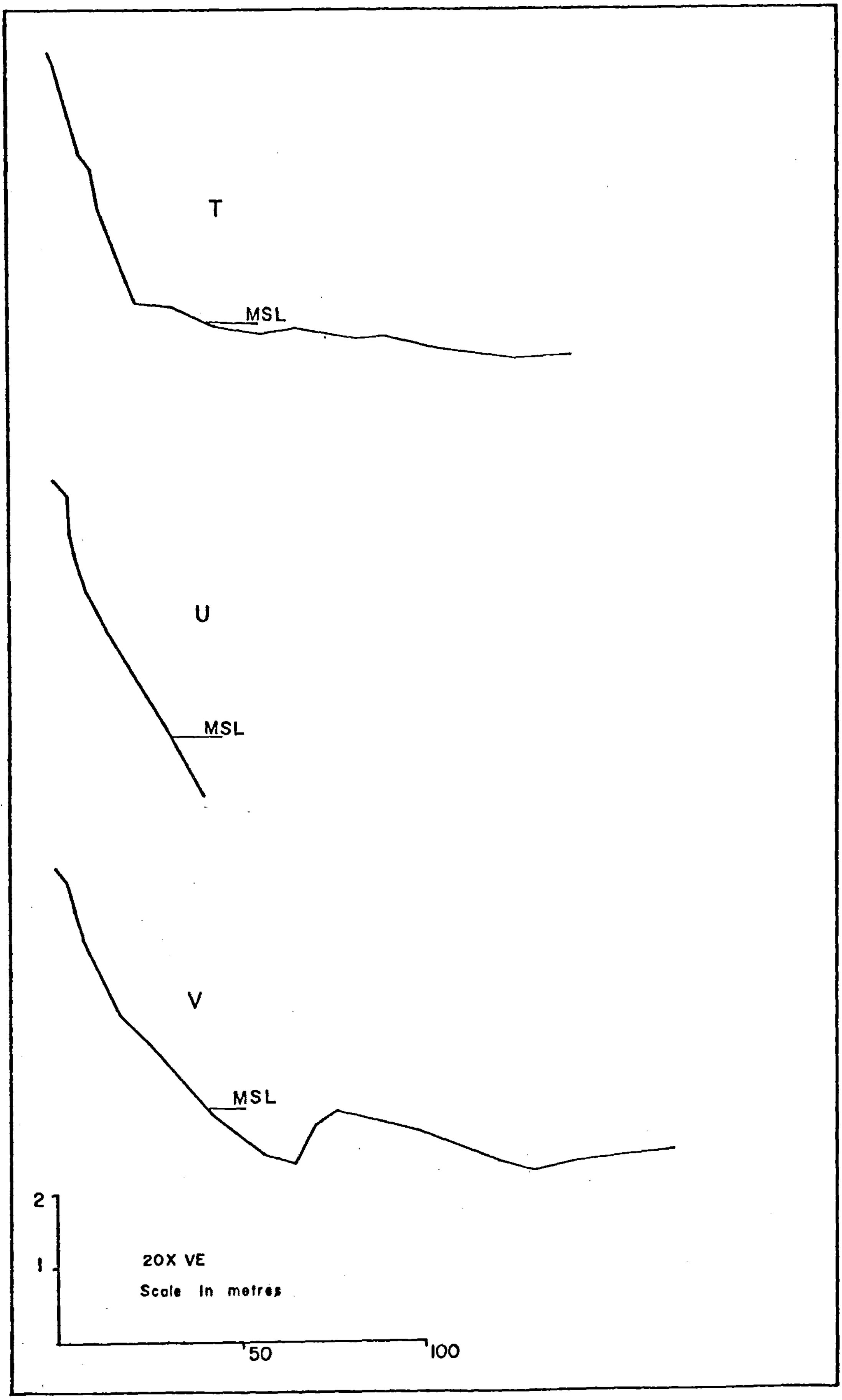


Fig. 4. 5 (Continued)

The following two major beach types may be identified in Golden Bay but it should be noted that within these two there exist a number of subtypes, based on variations due to sediment types and morphologic forms.

I Protected Sand and Gravel Beaches.

These beaches lie in a relatively sheltered area of Golden Bay where the wave energy is generally lower. The profile locations in this area are sites A, B, C, D, E and F.

The beach face slope is primarily governed by the type of beach sediment. The beaches which are composed of very coarse or pebble size sediments have the steeper beach gradients (5-7^{o}), as found at sites B, C, D and E (Fig. 4. 5 and Plate 4. 1). The beaches with finer grained materials, sites A and F (Fig. 4. 5 and Plate 4. 3), have less steep gradients of 2-3^{o}.

The width of the beaches are very narrow, approximately 20 m; this is significant as during storm periods the waves are able to reach a greater area of beach than where there are greater beach face widths. Only the finer grained beaches, sites A and F, within this area develop berms. This reflects the inability of the low wave energy to significantly redistribute the coarser grained sediments within the beach.

The width of the tidal flat is at a maximum in these profile types, in excess of one thousand metres. The well packed sand flats are very gentle in gradient and do not exhibit, to the same extent, the ridge and runnel systems which develop more extensively in the more exposed areas of Golden Bay. This suggests that the sand on the tidal flat, which is held together by the extensive growth of Zostera napa or eel grass (Plate 4. 4), is unable to be moved onshore in any significant amount. However, during storm periods the wave energy is sufficient

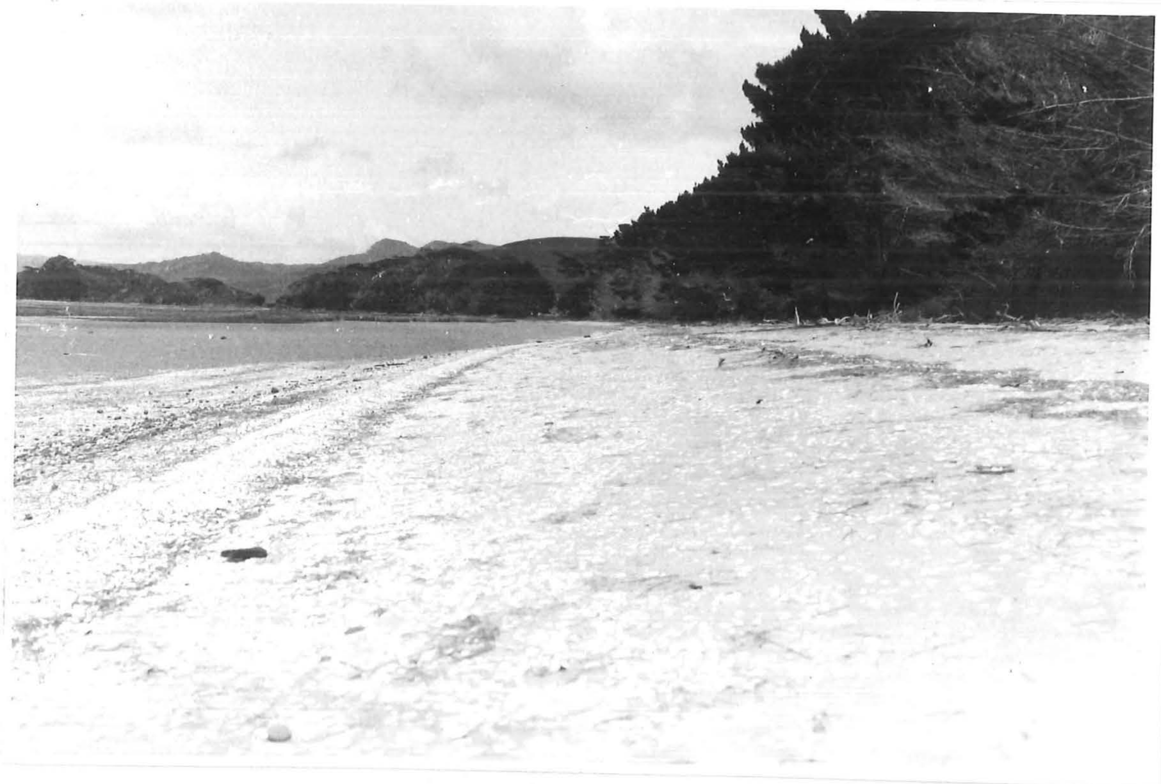


Plate 4. 3 - Beach area at site 1, A.

Plate 4. 4 - Intertidal flat at site 1, A.

to move some sediment and plant material onshore as seen in Plate 4.5 which shows the building of wrack, tidal flat plants which have eroded from the flat, at site A.

The extensive tidal flats help to disperse the wave energy to a great extent, as the refraction diagrams in Chapter Three show. The refraction of the wave crests produces small refraction factors which indicate significant wave energy loss in this area. Davies (1972) states that beaches exposed to low wave energy attain steeper beach gradients. Thus this secondary control on the beach form will help to maintain a steep beach gradient for those coarser grained beaches.

II Exposed Sandy Beaches.

The beaches that fall within this category generally have sand sized beach sediments and are exposed to higher wave energies. As for the beaches of type I a number of subtypes may exist within this broader classification. These subtypes may be defined by local variations in beach sediment textures or morphology or degree of exposure to wave energy.

Exposed sandy beaches occur from Pakawau, site G to Wainui Inlet, site V (Fig. 4.1). The beaches are backed by low dune cliffs (Plates 4.6, 4.7) which are reached by wave action only during spring tides or storm periods (Plate 4.8). The beach width is slightly greater than on the beaches previously discussed for type I; that is, approximately 35 m as compared to 20 m.

The beaches with coarser sediments have steeper beach gradients (5-7^{o}), especially the beaches which are comprised of weathered granite as found at sites T, U and V. The finer grained beaches have less steep gradients (2-3^{o}), as found at sites L, O, R and S.

Plate 4. 5 - Buildup of wrack at site 1, A.

Plate 4. 6 - Low dune cliff and beach area at site 21, R.

Plate 4.7 - Low dune cliff and upper beach on Parapara Spit.

Plate 4.8 - Severely eroded dune cliff at Pohara Beach. Small storm waves operating just after High Tide.

The extent of the tidal flat in front of these beaches varies considerably. The intertidal flat is most extensive where rivers enter Golden Bay and form ebb tide deltas, as found at the mouths of the Aorere and Takaka Rivers (Plate 4.9). By comparison the tidal flat is less extensive and has a much steeper gradient at sites H, I, J, L, M and N (Figs 4.5 and 4.1).

The sediment on the tidal flat is less well packed than found on the tidal flats discussed for type I, so that a greater degree of onshore-offshore exchange of sediment is expected. When high energy wave conditions are occurring a ridge and runnel topography is likely to develop. Davis et al. (1972) discuss the formation of these features for both tidal and non-tidal environments in North America. Similar controlling factors for the formation of these systems may be applied to the Golden Bay situation.

The ridge and runnel system is not always evident on the tidal flat but formation will take place after storms. The higher energy waves during the storm will provide sediment from the nearshore and beach for the formation of the ridge and runnels. During the following calm periods the ridges migrate shoreward with the tidal cycle and eventually "weld" on to the beach. As subsequent ridges migrate on to the beach multiple berms may develop on the beach face. These ridges and runnels are shown by profiles G, J and T on Figure 4.5 and by Plate 4.10. An extensive high tide berm may develop on the beach during prolonged calm periods, typically during the autumn-winter period (Plate 4.11).

4.3.4 Beach Dynamics.

<u>Beach Envelopes.</u>

King (1972) and Davies (1972) discuss periodic cut and fill sequences on a beach profile in relation to the shape of the beaches'

Plate 4. 9 - Ebb tide delta at the mouth of the Takaka River.

Plate 4. 10 - Ridge and runnel system on intertidal flat, site 8,G.

Plate 4.11 - Large high tide berm built on the beach at site 8,G. during the autumn-winter period.

sediment prism or sweep zone. This sweep zone or beach envelope is the beach area bounded by the upper and lower profiles surveyed during the study period. Davies (1972) proposes that on beaches where there is considerable periodic cut and fill sequences the sweep zone may be a deep one and beaches will exhibit shallow sweep zones if there is little cut and fill.

The sweep zones for the beaches profiled in Golden Bay were drawn up and the summary of the areas bounded by the sweep zones is shown in Table 4.3 and in Figure 4.6 by profile sites, A, D, E, H, J, M, O, S and T.

As shown by Table 4.3 the beaches exposed to an annual lower wave energy, the protected sand and gravel beaches, have a lower magnitude of volumetric beach change. The finer grained beaches have a greater relative amount of change (sites A and F) of approximately 40 m^3/m. The coarser grained and especially the gravel beaches (site D) have lower relative magnitudes of change, in the order of 8-20 m^3/m.

As stated by Davies (1972) these narrow beach envelopes reflect beaches which have little periodic cut and fill sequences and hence remain relatively stable during the year. The beach face reflects less change than that measured on the tidal flat area, for these profile sites; this suggests that sediment is moved through the beach zone in a longshore direction but not on to the upper beach area.

The sweep zone areas measured for the beaches located in the more exposed area of Golden Bay, sites G to V, are generally deeper, in the order of 40-100 m^3/m. This indicates greater amounts of cut and fill. The finer grained beaches, sites J, L, O, P, R and S show higher magnitudes of change, in the order of 70-100 m^3/m. The coarser

Table 4.3 - Sweep zone areas for surveyed beaches from December 1978 to June 1979.

Beach Location	Sweep Zone Area m^3/m
A	40
B	28
C	17
D	8
E	21
F	37
G	28
H	58
I	58
J	80
K	55
L	101
M	63
N	58
O	70
P	61
Q	14
R	68
S	76
T	37
W	41
V	56

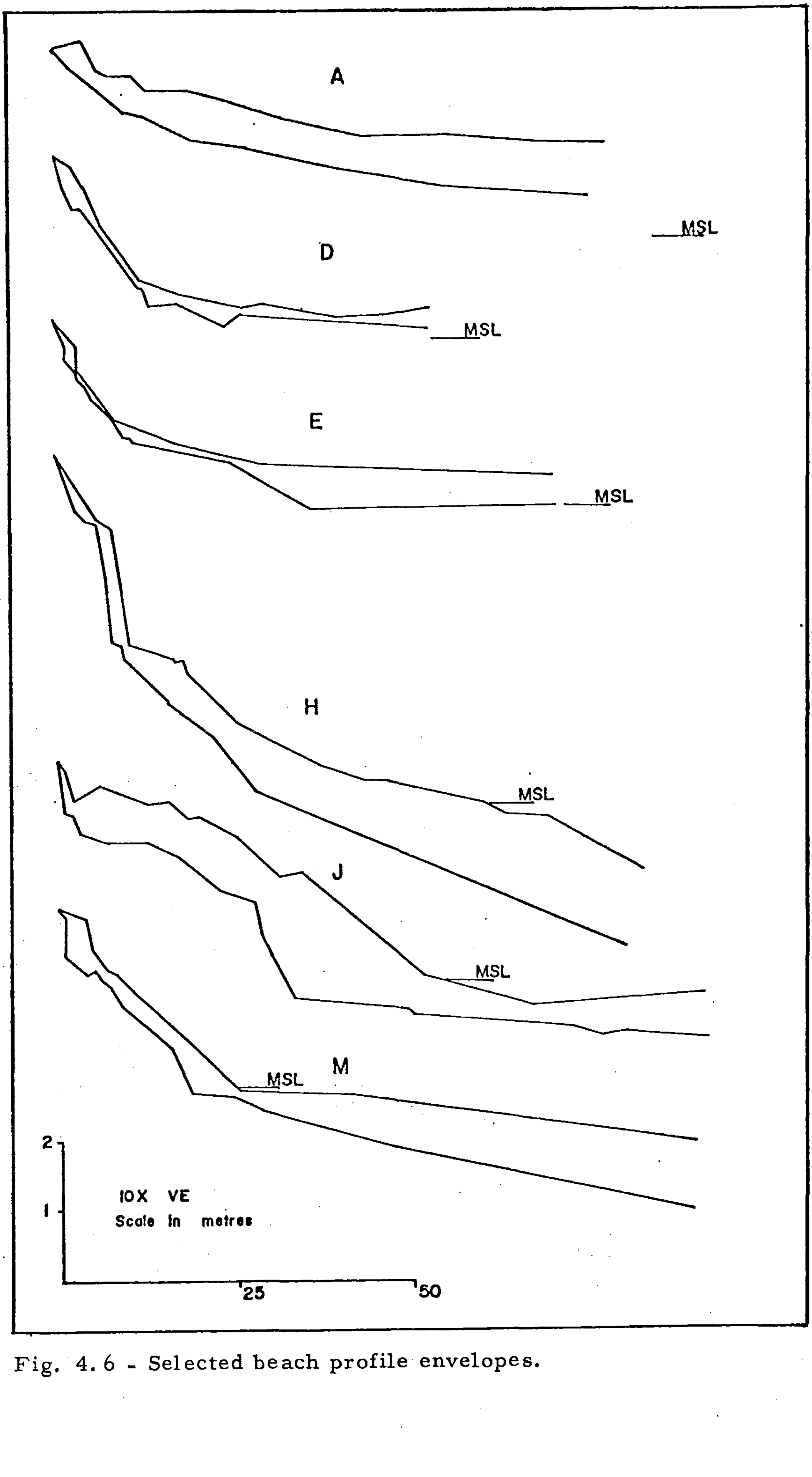


Fig. 4.6 - Selected beach profile envelopes.

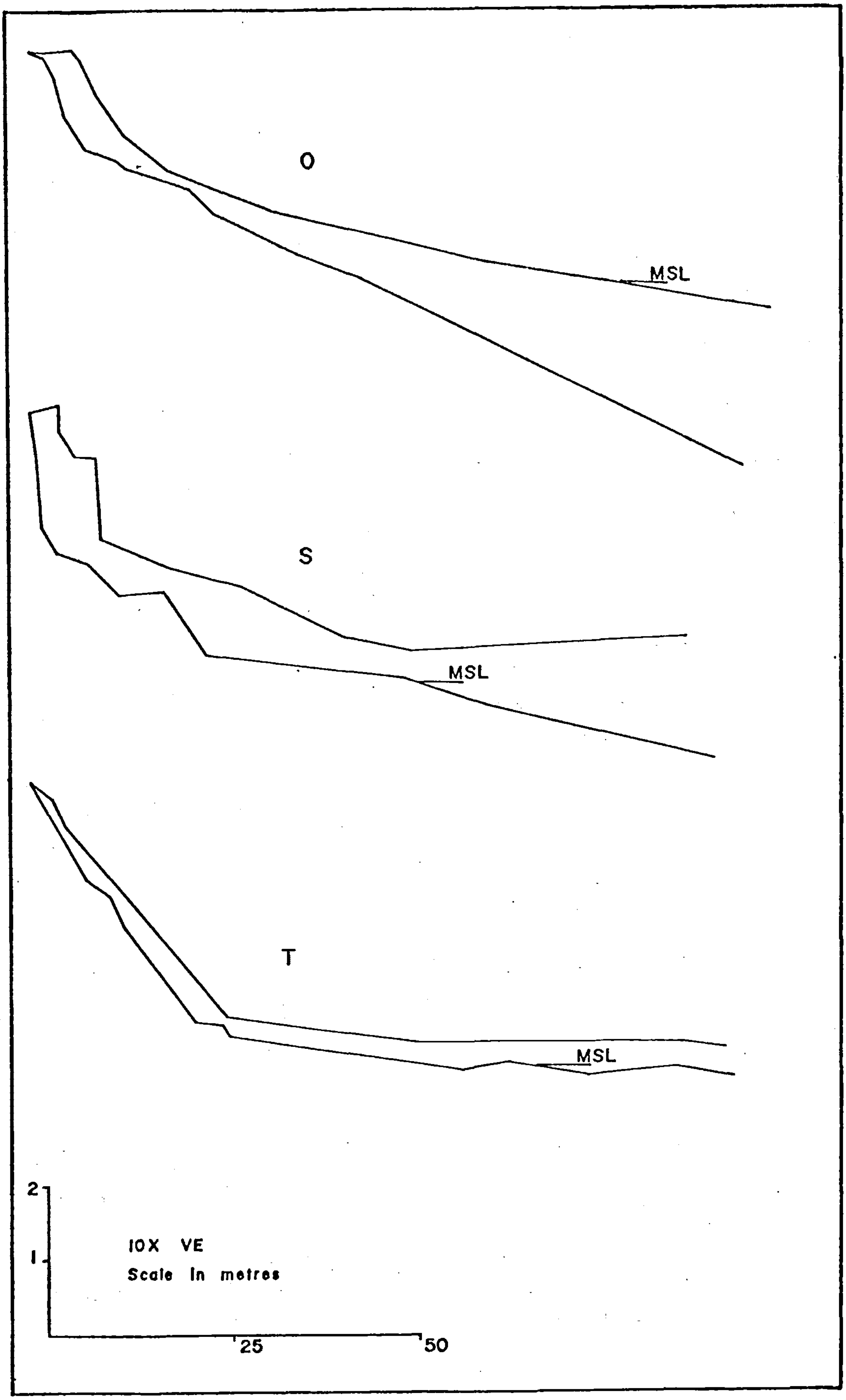


Fig. 4.6 (Continued)

grained beaches at sites T, W and V show less amounts of change, in the order of 40-60 m^3/m.

Therefore it would appear that the amount of change occurring on a beach is a function of the degree of exposure to wave energy and the sediment grain size of the beach. The volumetric change measured for the more exposed beaches in Golden Bay compare closely to those measured by Healy (1978) for the Bay of Plenty region (40-70 m^3/m). The higher energy coast of the Canterbury Bight has sweep zone volumes typically in the order of 150-250 m^3/m (Kirk, 1979). Thus the magnitudes of the beach envelopes for Golden Bay are quite considerable, especially for the exposed beaches, given a low wave energy environment which is influenced occasionally by storm induced waves.

Periods of Beach Profile Change.

Figure 4.7 illustrates the typical type of beach profile change which occurred during the study period. The amount of beach change from one survey period to the next was determined by measuring the area under the beach profile at each survey time. These changes were determined as cross-sectional areas in m^2. The areas were measured with an electronic digitizer. This method does not allow direct comparison between profile sites as the limits to which the profile area were measured varies for each profile site. It is, however, possible to ascertain whether cut or fill has occurred between survey periods and to propose general trends of beach change for all profile sites during the survey period. Table 4.4 summarises the amount of change measured for each profile site during the study period.

The trends summarised in Table 4.4 support the proposals put forward in Chapter Three and which were based on wind and wave data. It was argued that the spring-summer period would be a time of rougher

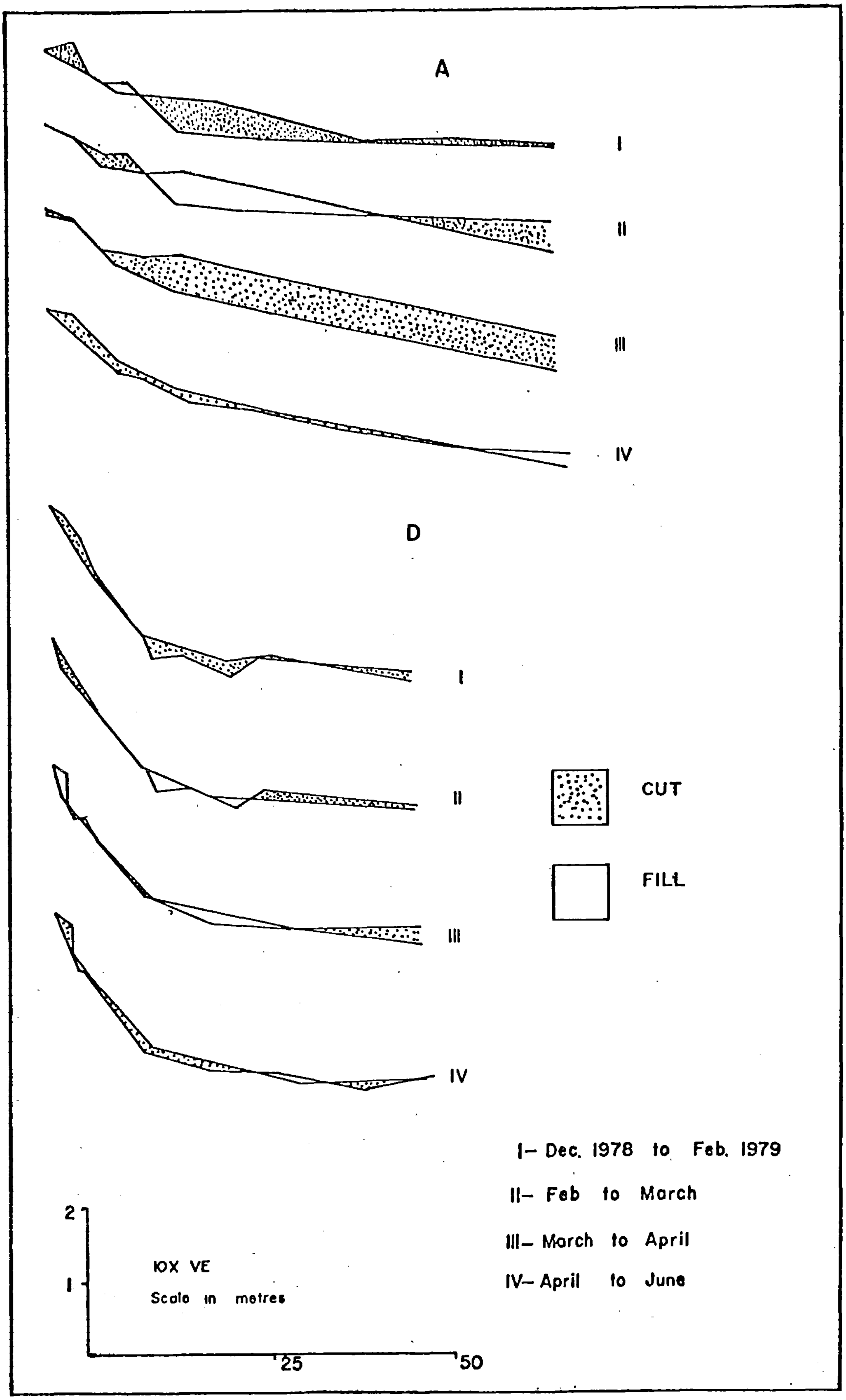
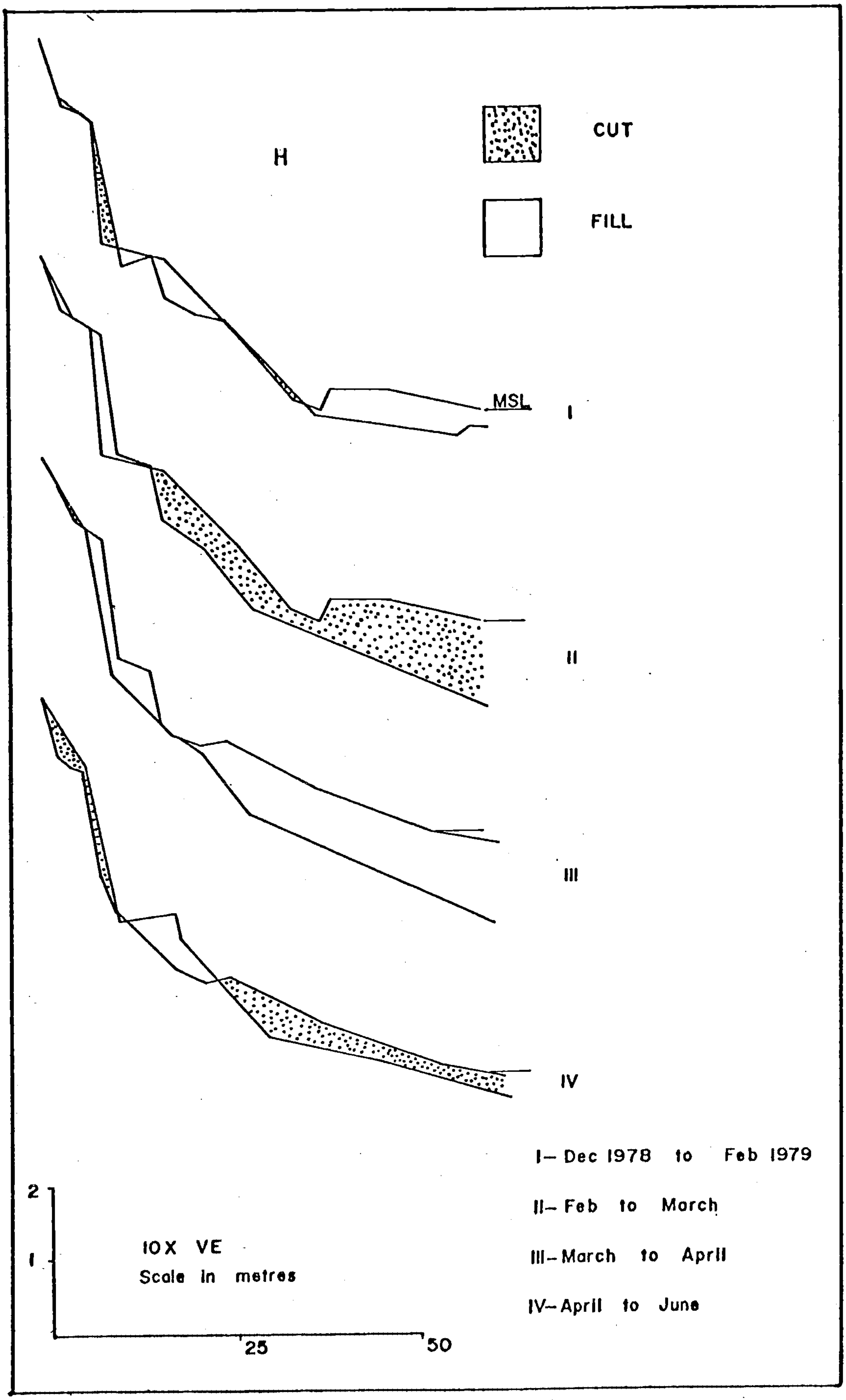


Fig. 4.7 - Time sequence of beach profile changes for selected locations. (Note: MSL not shown on profile sites A and D.)



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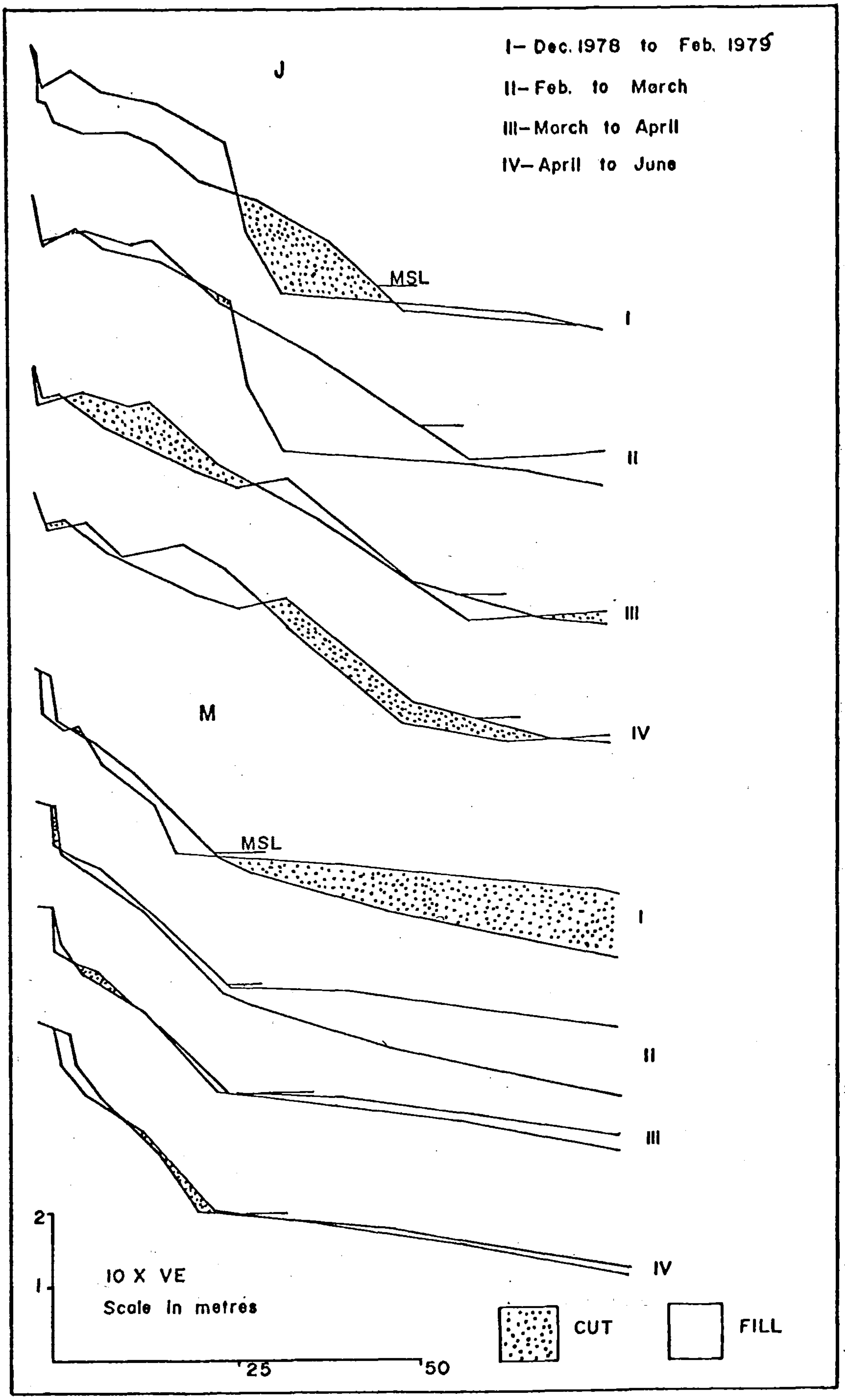

Fig. 4. 7 (Continued)

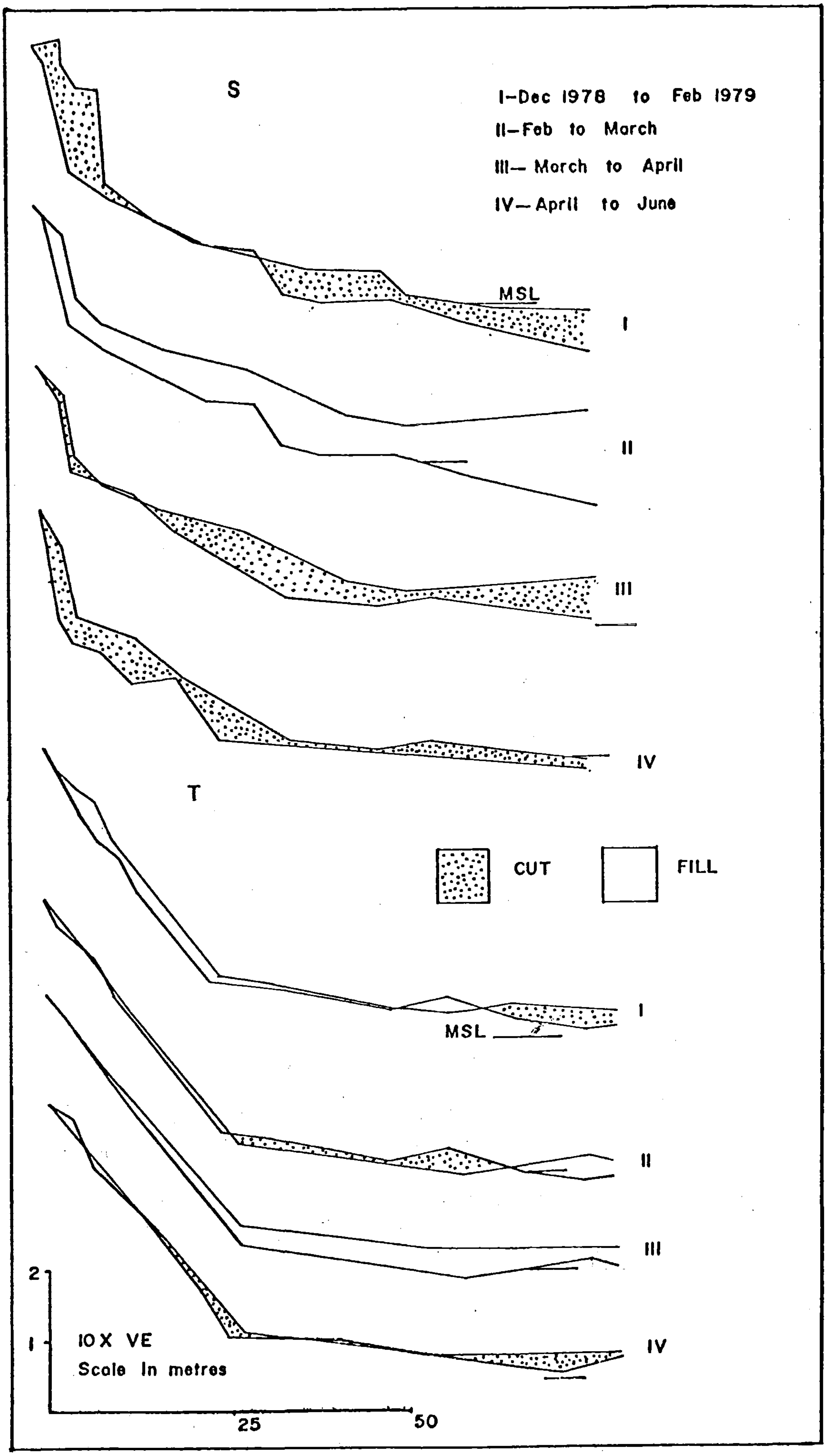

Fig. 4.7 (Continued)

Table 4.4 - Summary of beach profile changes, showing the frequency of types of change (cut, fill or stable) and the dominant change for each survey period. Stable is defined as a change of $\leqslant 5\ m^2$.

Survey Period	Frequency of Profile Change Type %			Dominant Change Type
	Cut	Stable	Fill	
I Dec. 1978 to Feb. 1979	59 (13/22)	27 (6/22)	14 (3/22)	Cut
II Feb. to March	23 (5/22)	18 (4/22)	59 (13/22)	Fill
III March to April	23 (5/22)	50 (11/22)	27 (5/22)	Stable
IV April to June	32 (7/22)	59 (13/22)	9 (2/22)	Stable

sea conditions and hence beach erosion would be more likely. The autumn-winter period is a time of calmer sea conditions and hence more stable or accretional beaches would be likely.

The beach morphological changes shown by Figure 4. 7 reflect the cut and fill periods as the beach responds to variation in wave energy and sediment characteristics.

The beaches located in the sheltered wave energy zone of Golden Bay (sites A and D in Figure 4. 7) show less periodic cut and fill exchanges. The finer grained beaches, for example site A, do show greater relative amounts of change. As discussed previously there is less exchange of sediment between the beach face and tidal flat than occurs on beaches in the more exposed part of Golden Bay. Generally the beaches are stable for a greater period of the year due to the predominantly lower wave energy.

The beaches in the more exposed areas of Golden Bay reflect the spring-summer cut and autumn-winter fill pattern identified previously. Profile sites H, J, M, S and T (Fig. 4. 7) reflect these changes to some degree. During beach erosion periods material is removed from the beach face area and deposited on the intertidal flat. The beach face angle becomes steeper during beach erosion. Extensive beach erosion may result, in the dune cliffs backing the beach being cut into, during storm periods as shown by site S in Figure 4.8 during the first survey period (Plate 4. 8). During beach accretion phases the beach gradient becomes less steep and a large berm may build up as evident on site H (Fig. 4. 7) and Plate 4. 11.

As stated previously the beaches surveyed, especially those located in the more exposed wave energy area, display considerable beach sediment exchange for a low wave energy environment. These changes can be accounted for by the extreme water level variations associated with spring tides and storm induced waves from the north-east and north-west, which act for short time periods. Sea level rises due to the spring tide may enable waves to reach 0.9 m vertically further up the beach and so work a greater area of beach. Sea level increases due to storm surges, coupled with wave setup, may be in the order of 0.9 m. These water level variations that accompany changing wave conditions enable the waves to work a greater area of beach, especially during rough sea conditions, and hence large amounts of beach material are redistributed within the beach system over a short period of time. These short term fluctuations in beach form also have a distinct seasonal aspect, previously identified.

4.4 SUMMARY

The investigations of beach sediments and morphology have indicated the nature of spatial and temporal variations around the Golden Bay coastline.

The beach sediments of Golden Bay are predominantly medium to fine sands which are well to very well sorted. Local deviations from these characteristics result from local sediment sources, such as granite cliffs and relict, river gravel deposits. The sorting of the beach sediment is a function of both sediment source area characteristics and hydraulic factors. The percent of shell material in sandy beach sediments varies from 1.0% to 47.0% with the beaches in the northern part of Golden Bay generally containing larger amounts.

Short term variations in beach morphology and dynamics have been considered. The beach form and dynamics are functions of sediment characteristics, degree of exposure to wave energy and the associated increases in water levels with increasing wave energy.

The beaches in the northern part of Golden Bay lie in a sheltered zone in terms of exposure to wave energy. The beaches reflect this and show volumetric changes in the order of 20-40 m^3/m. The more exposed beaches in the southern parts of Golden Bay show beach envelopes in the order of 40-80 m^3/m. The analysis of change in profiles during the study period showed that the spring-summer period was a more erosive period and that the autumn-winter period was a time of beach accretion and stabilisation. These findings support the hypotheses developed in Chapter Three.

The Golden Bay coastline therefore is very different from other areas of the New Zealand coastline previously studied. The seasonal pattern of summer cut and winter accretion as found in Golden Bay contrasts markedly with the reverse pattern commonly identified elsewhere. The relatively large amounts of short term beach change are a function of the extreme water level variations accompanying changing wave conditions, so that waves may work a further 0.9 m vertically up the beach during spring tides. Together these factors act to induce relatively frequent and large amounts of beach cut and fill, with a distinct seasonal aspect.

CHAPTER FIVE

RECENT SHORELINE CHANGE

5.1 INTRODUCTION

The Golden Bay coastline has been classified by McLean (1978) as a depositional coast which has undergone substantial progradation during the Holocene. This progradation has continued for the most part of the last few hundred years due to relatively low wave energy conditions and a continuing abundant supply of sediment. In contrast to this, surveys carried out on sandy shores elsewhere in New Zealand (Kirk, 1977a) and around the world (Bird, 1976) show that progradation has slowed or ceased so that the natural trend of most sandy shores is either a delicate state of stability or active erosion. It has been observed by Berqurst _et al._ (1975) and Kirk (1977b) that stagnation and erosion of the shoreline are local occurrences only in Golden Bay.

The purposes of this chapter are to determine the amounts of recent coastline change which have occurred in Golden Bay, especially where erosion has been evident, and to determine the spatial variation of this change. Also a review of shoreline protection measures used to combat erosion in Golden Bay will be presented.

5.2 SCALE OF COASTAL CHANGES

It is possible to consider beach and coastal changes as occurring over a range of spatial and temporal scales. Schwartz (1968) employed this approach to describe the Bruun effect of sea level rise as a permissive factor in shore erosion (Bruun, 1962). Table 5.1 presents a

Table 5.1 - Time scale of beach and coastal change.
(Source: Gillie, 1979, p. 110)

Time Scale (Years)	Geological and Environmental Factors Producing Changes	Response Magnitude. Horizontal Change. (Metres)
Short Term ($\leqslant 10^{-2}$)	- Single storms, storm surge. - Tidal variation.	$\pm$ 0.1 to 5.0
Seasonal and Annual (10^{-1} to 10^{0})	- Periods of storms and high sea levels. - Seasonal variation in sea conditions.	$\pm$ 1.0 to 25
Historical (10^{1} to 10^{2})	- Storm cycles and sea level changes. - Sediment budget changes.	$\pm$ 10 to 50
Long Term (10^{2} to 10^{3})	- Post-glacial sea level rise to near present.	$\pm$ 50 to 100

time and spatial magnitude scale which indicates the relative position of the scale of coastal change discussed in this chapter. The scale is based first, on time intervals over which characteristics of geologic and physical environments can be expected to change and, secondly, on the magnitude of the spatial response which is likely to be produced in the beach or coastal system by these changes.

The discussion on beach dynamics investigated changes which are due to events occurring between 10^{-2} and 10^{0} years. The following discussion on recent shoreline change pertains to changes as occurring over an interval of 10^{1} to 10^{2} years, specifically over the last 30 years.

5.3 METHODS OF DETERMINING RECENT COASTAL CHANGE

Coastal change was determined through three methods.

First, recognisable coastal features were compared between two sets of air photographs. These air photographs were made in 1952, 1967 and 1972. The coastal features most commonly used for comparison were the vegetation line and the most seaward dune edge. Positioning control for comparative measurements was achieved in two comparative ways. For single point measurements distances were measured from coastal features to permanent features visible on both photographs. The permanent positions were chosen near the shoreline to reduce radial distortion effects and included the corners of houses and road edges. For comparing lengths of shoreline a Zeiss sketchmaster was used. This instrument enabled the shorelines on different air photographs to be superimposed allowing for control points and different scales. The shoreline was then traced off for each air photograph period, 1952, 1967 and 1972.

The second method used in ascertaining coastal change entailed the use of Survey and Deposited Plans. These plans were available only for certain sections of the coastline and were made at various dates, the earliest being 1898 and the latest 1976. The distance from the shoreline to fixed survey pegs was measured for various time periods and the change in distance compared. These survey plan distances were also compared to distances worked out from air photographs.

Finally certain sections of the 1979 coastline were compared to the 1972 air photograph coastline by tape measuring the distance from the shoreline to permanent positions recognisable on the 1972 air photographs.

5.4 ESTIMATES OF ERROR

Errors in the measurement of coastline change arise from variations in scale of the air photographs and Survey and Deposited Plans and the accuracy to which one can measure the distances from shoreline to fixed positions. Inaccuracy may also arise due to differing interpretations of the seaward boundary of the land by surveyors. Surveys are required to mark the position of ordinary high water averaged over not less than one year, but this is recognised and interpreted in the field in different ways (Gibb, 1978). Some plans use vegetation lines while others use drift line as seen on the beach or the high water mark may be plotted in terms of local tidal datum. Problems such as these account for an unquantifiable amount of noise in any investigation of sequential changes in shore position.

In this study the smallest useful measurable distance was taken as $\pm$ 0.2 mm which represents $\pm$ 3.2 m at a scale of 1 : 16000. Therefore in comparing two photographs the error is doubled and allowing for additional sources of error the total margin of error should be in the order of 8.0 m. Thus in the following descriptions of coastal change measurements less than or equal to 8 m have been considered as indistinguishable changes in shoreline position.

5.5 ANALYSIS OF SHORELINE CHANGE

Abel Head to Pakawau.

The coastline north of Pakawau (Fig. 5.1) shows relatively little change when reviewed over the period of air photo coverage, 1952-1972. There are periods of increasing and decreasing vegetation cover on the tidal flats but this is probably a function of fluctuations in the degree of storminess in Golden Bay. Calmer periods of sea conditions are likely to lead to increased vegetation growth and a stabilising of the intertidal flats.

Pakawau to Waikato.

Changes in the shoreline between Pakawau Inlet and Waikato (Plate 5.1) indicate that this part of the Golden Bay coastline has undergone periods of relatively extensive shoreline erosion. The amount of erosion on the Pakawau Spit is in the order of 40 m since 1921 while further south towards Waikato the amount of erosion is similar but has occurred mostly since 1952. This suggests a faster rate of shoreline erosion in the central regions of this section. Sediment supply is very restricted due to a net local sediment transport direction, near the Ruataniwha Spit, which inhibits sediment movement into the eroding area. The shoreline of the Pakawau Spit receives sufficient sediment from the Pakawau Inlet to replenish the beaches and hence slow down erosion rates.

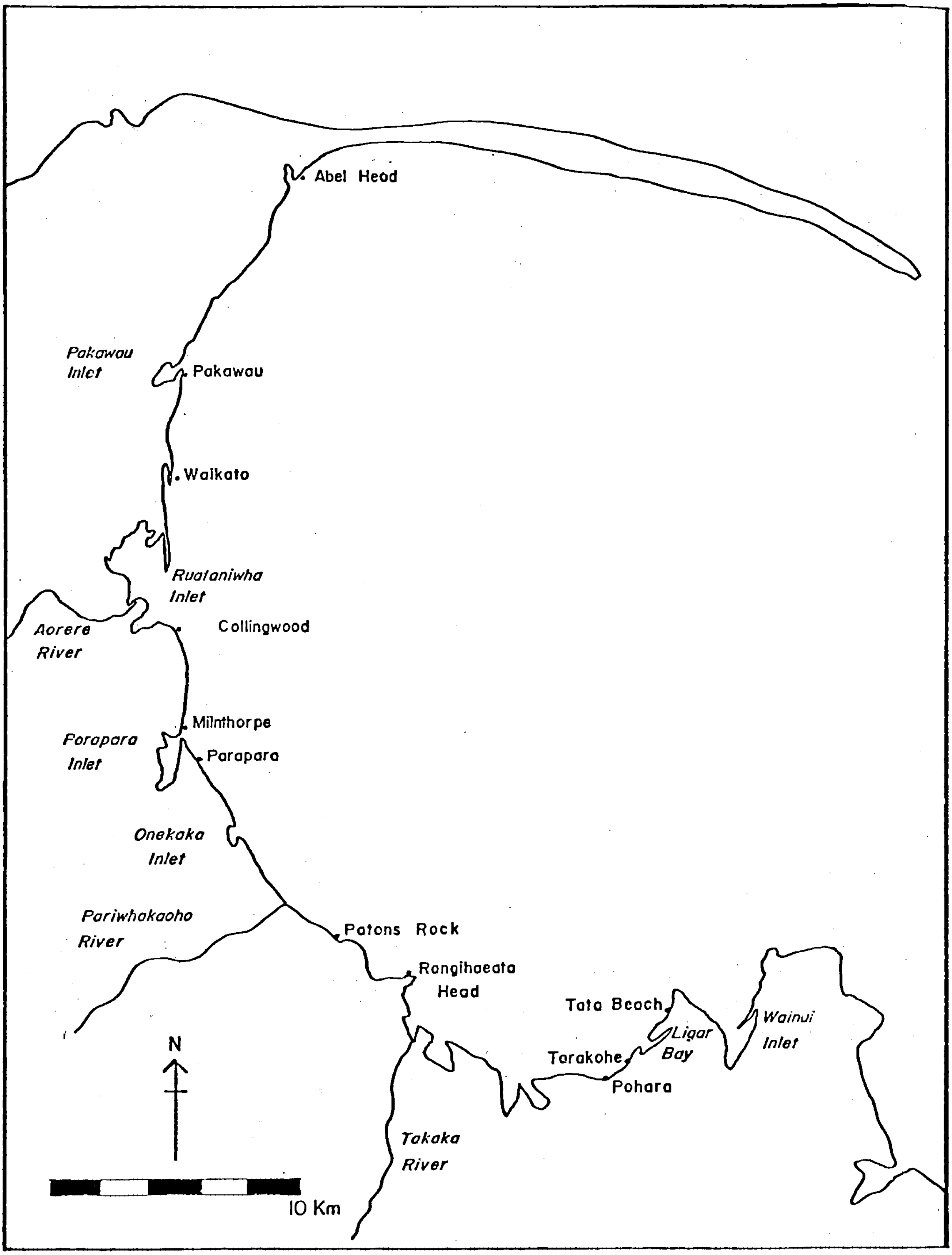

Fig. 5.1 - Specific locations along the Golden Bay coastline.

Plate 5. 1 - Highly eroded dune cliff, between Pakawau and Waikato.

Plate 5. 2 - Prograding beach, to the north of Parapara Inlet.

The erosion is primarily induced by storm waves. To some extent erosion rates are masked because one severe storm may account for all erosion observed over a 20 year air photograph coverage period. The recent severe erosion at the Pakawai Motor Camp, 16 m since 1973, and at Waikato present serious problems due to man's development in the area which will be discussed later.

Waikato to Onekaka Inlet

The coastline between Waikato and the Onekaka Inlet (Fig. 5.1) displays relatively little change over the past 30 years, except for the spit complexes which appear to be prograding (Plates 5.2 and 5.3). The Parapara Spit has a history which closely parallels that of other spit complexes in Golden Bay. Sand is added to the distal portion of the spit at a rapid rate. Kirk (*in* JASMAD Report, 1977) shows that 3.9 hectares of sand has been added to the spit in the form of new beach ridges, from 1904 to 1976. The sediment is moved on to the spit from the beaches to the east (Plate 4.7) which remain stable due to an abundant sediment supply.

Onekaka Inlet to Pariwhakaoho River.

The cliffed coastline between the Onekaka Inlet and the mouth of the Pariwhakaoha River (Fig. 5.1) is undergoing very slow erosion. Even though the cliffs are composed of very soft mudstone the low wave energy environment in Golden Bay results in a very small erosion rate. An estimate of the rate can be formed if we assume present sea levels for 5-7000 years and a shore cut platform width of approximately 200 m. This results in a rate of erosion of 0.03 to 0.04 m yr^{-1}. The erosion

Plate 5. 3 - Stable to prograding beach to the south of Waikato.

Plate 5. 4 - Shore platform, covered by sand; south of the Onekaka Inlet.

of the cliffs has resulted in the formation of a shore platform, exposed at low tide, which is often covered by a thin veneer of sand as shown by Plate 5.4.

Pariwhakaoho River to Patons Rock.

The coastline along this section is supplied with abundant sediment from the eroded cliffs and from the Pariwhakaoho River. This results in a very stable to prograded coast. The shoreline near Patons Rock has prograded by up to 18 m during the period 1937 to 1958 and appears to be continuing at present.

Patons Rock to Rangihaeata Head.

Extensive erosion has occurred on this section of coastline as suggested by the present-day shoreline and shown by Plates 5.5 and 5.6. Survey plans for the period 1881 to 1972 show that the coastline has eroded from 18 to 40 m. The exposed marsh deposits and relict headland (Plate 5.5) indicate that the erosion has been occurring for a long time. While the inter-plan rate of erosion is slow, 0.4 m yr^{-1}, the rate may be greatly accelerated during storm periods. The two headlands, Patons Rock and Rangihaeata Head, restrict any sediment from entering this section of coastline and hence the beach system is undernourished.

Rangihaeata Head to Tarakohe.

Except for a serious erosion problem at Pohara Beach, this section of coast is very stable or prograding. The Takaka River supplies supplies abundant sediment to the beaches, but little detectable change is evident from the air photographs.

The shoreline erosion at Pohara Beach reflects its position at the updrift and of a longshore transport system that has a net sediment

Plate 5.5 - Exposed marsh deposits and relict headland at Rangihaeata Head.

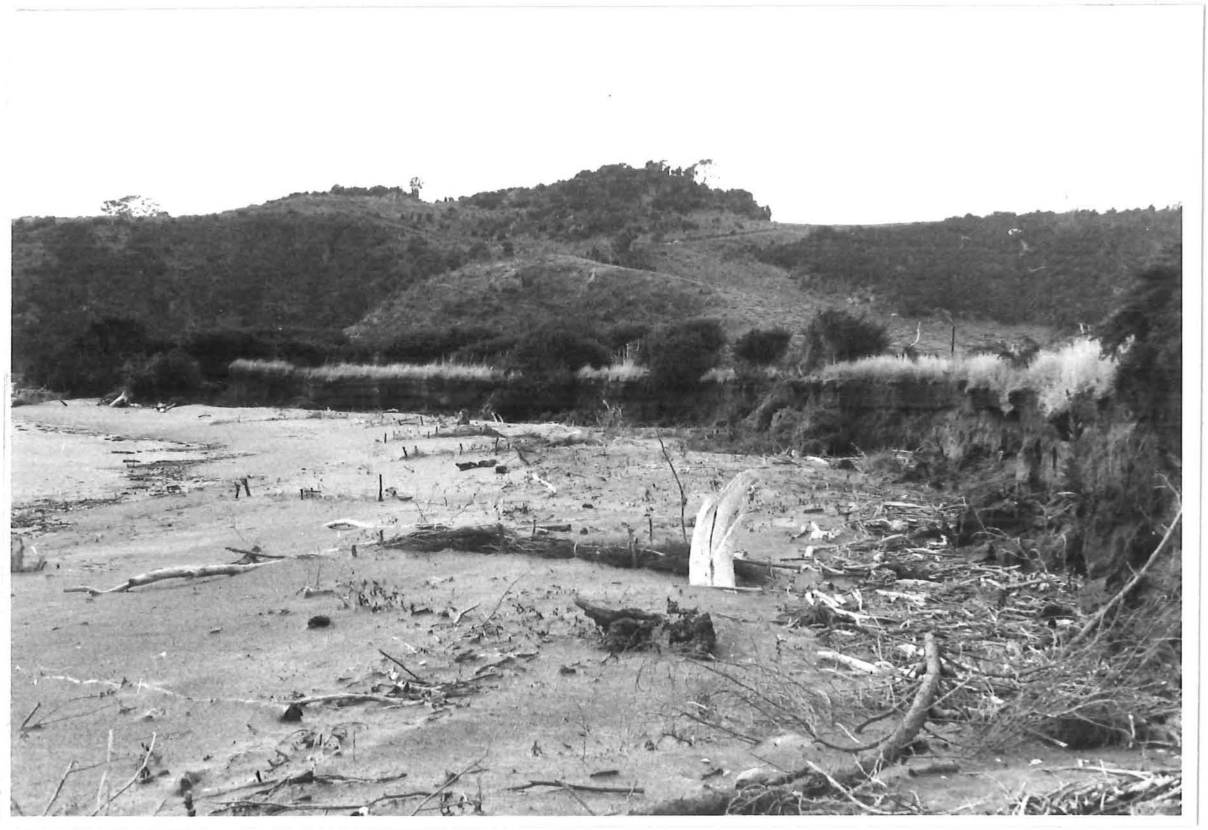

Plate 5.6 - Severely eroded beach area at Rangihaeata Head.

transfer toward the west; correspondingly the amount of shoreline erosion decreases toward the west. Surveys show that up to 29 m of beach front was lost between 1952 and 1967 and another 12 m of erosion occurred between 1972 and 1974. These erosion problems have created serious coastal management probelms as discussed by Kirk (1978a and b), and reviewed later in this chapter.

Tarakohe to Wainui Inlet.

The coastline in this area is characterised by a cliffed coast broken up by small, independent pocket beaches. This section of coastline has shown very little change over the past 30 years because the limestone and granite cliff s are very resistant to weathering and erosion. However the spit complex enclosing Wainui Inlet (Plate 5. 7) has prograded. The spit acts as a salient trap for the weathered cliff sediment which is moved in a net westerly direction. The length of the spit has decreased by approximately 130 m between 1952 and 1972 but its width has increased, especially the updrift and where the width has increased from 16 m to over 48 m. The present spit form suggests that the length and the width of the spit may be increasing significantly.

5.6 REVIEW OF COASTAL CONTROL MEASURES

As shown by Table 5. 1 the length of shoreline in Golden Bay presently subject to phases of erosion, intermittent or continual, is approximately 9. 0 kms of which 7. 0 kms is developed for housing, recreational use or farming. This 7. 0 kms is only 13% of a total exposed coastline length of 54 kms.

Even though this is a relatively small section of the total Golden Bay coastline, the problems arising due to the erosion of the

Plate 5.7 - Spit complex enclosing Wainui Inlet.

Plate 5.8 - Coastal protection measures used at Pakawau, rockfill and wooden piles.

TABLE 5.1 - Length of coastline subject to erosion.
(Compiled from air photos, survey plans and 1 : 63,360 scale NZMSI sheets S1, S3 and S8.)

Location	Distance of eroding shore (kms)
Pakawau Spit to Waikato	4.7
Cliffs between Onekaka and Pariwhakaoho River	2.0
Rangihaeata Head	1.5
Pohara Beach	0.8
Total	9.0

shoreline are serious because these sections of coastline are prime recreational areas as well as ideal locations for holiday homes. There is pressure for further subdivisions, campgrounds and provision of coastal reserves.

As indicated by the previous discussion on the analysis of shoreline change the most serious erosion problems in relation to man's land development schemes are at Pakawau, Waikato and Pohara Beach.

Pakawau and Waikato.

The primary erosion of the beach face and low dune cliff occurs during storm periods when storm waves operating at increased water levels remove large amounts of sand offshore. Due to an insufficient sediment supply the beach system is not fully renourished before the advent of another storm.

The erosion of the foredune in this area is creating problems for the housing developed on the narrow backshore area. In an effort to protect their properties the houseowners have established control measures which have only served to compound the problem. The type of protection measures (Plates 5.8 to 5.14) commonly used are rock fill, wooden piles driven into the beach in front of the dune face and brush fences. These measures only serve as a trap for wind blown sand and as such only act as a buffer for very small waves. The rock fill which is widely used for protection has two major disadvantages. Firstly, waves will scour the beach in front of the rock fill thus removing any beach face that may exist. Secondly, if the rock fill is not continuous along a section of coast, as found in this area, increased erosion problems will eventuate on adjacent unprotected property. This is because the rock fill only provides protection for the beach immediately behind the rock revetment and unprotected

Plate 5.9 - Artificial dune formed to protect Pakawau Motor Camp, before storm wave attack.

Plate 5.10 - Artificial dune at Pakawau Motor Camp after storm wave attack.

Plate 5.11 - Brush fences used for coastal protection at Waikato.

Plate 5.12 - Protection measures used on tip of Waikato Spit.

Plate 5. 13 - Discontinuous protection measures at Waikato.

Plate 5. 14 - Various types of coastal protection measures along the foreshore at Waikato, i. e. rock fill, and brush fences.

adjacent property will be scoured at a great rate. Therefore any structure or revetment designed to protect the shoreline should encompass the whole section of coastline likely to be severely affected by storm wave attack.

As outlined previously, the Pakawau Spit has shown shoreline erosion of up to 40 m which is continuing at present. Serious problems may arise on this spit in the future if the proposed development of the spit proceeds, as sections of land are available for development that lie in the most severely eroded section of the spit.

II Parapara Spit

In contrast to the unstable situation of the Pakawau Spit, the proposed development on the Parapara Spit may proceed with less risk of erosion induced problems. As outlined by Kirk (in JASMAD report, 1977) the Parapara Spit distal end has exhibited pronounced growth during the last 70 years, which is continuing at present by the growth of beach ridges. The older proximal parts of the spit, which act as a feeder zone for the spit tip growth, have been stable for the past 70 years. This part of the spit already has successfully developed housing. The housing is located far enough back from the dune face so as not to cause damage to the foredune system which provides the best and cheapest defence against storm induced erosion.

Any future development on Parapara Spit should be sited so as to preserve the foredune system and maintain the vegetation cover on the inner dune system. The stable to prograding nature of the spit together with careful planning in the development stage, should ensure that erosion problems do not arise.

III Pohara Beach

A serious erosion problem occurs at Pohara Beach, which is a very popular summer holiday area in Golden Bay.

The erosion problem is of a natural origin and has been progressively worsening for the last 27 years. The primary cause of shoreline erosion at Pohara is a lack of incoming sand to replace that which is lost by a slow but persistant net transfer of sand along the shore to the west. In this respect Pohara is at the updrift end of the sand system and as such is most sensitive to changes in the supply of sand. There is little sand supply from the east and from the offshore area.

Kirk (1978a) has extensively researched the erosion problem at Pohara and in a further report (1978b) suggested suitable control measures which are being instigated at present. The scheme proposed by Kirk (1978b) involves beach nourishment by using material from the dredgings of Tarakohe Harbour. Pohara Beach fulfils many of the criteria identified overseas as being important in the choice of beaches suitable for nourishment, as outlined by Kirk (1978b). This scheme should reduce the erosion rate to an acceptable level and thus increase the lifetime of the beach system. If no action were to be undertaken Pohara Beach would continue to degrade and suffer intervals of severe erosion during storm periods.

It is evident from the discussion on control measures that careful planning is the key to success in controlling unstable shorelines.

Comprehensive prior planning at Parapara Spit would result in avoidance of severe erosion problems. An erosion problem may be compounded by unsatisfactory control measures as at Pakawau and Waikato, or be controlled if correct measures are instigated as at

Pohara Beach. Unsatisfactory control measures, as found at Pakawau and Waikato, have resulted because prior investigations into the causes of the problem were not carried out. Thus incorrect solutions to the problem have only compounded it. In contrast the erosion control measures proposed for Pohara Beach appreciate the causes of the problem and hence interact with the beach system processes and not against them.

Therefore it is extremely important that any future development of coastal areas around the Golden Bay coastline should be planned with a complete understanding of the coastal morphology and dynamics that exist on that area of coastline. The control measures forwarded to rectify erosion problems in one area cannot be simply transferred to another problem area because of spatial and temporal variations which exist in beach morphodynamics as detailed in Chapters Three and Four.

5.7 SUMMARY

The analysis of recent shoreline change around the Golday Bay coastline reveals a spatial variation which is a function of many interacting factors. The greater proportion of the exposed coastline is stable to prograding, while only 9.0 kms is subject to periods of erosion.

The stable to prograding sections of the coastline are in receipt of abundant supplies of sediment which continually nourish the beach systems and so enables quick restabilisation of the beach after periods of storm wave attack.

The sections of coastline subject to severe erosion are in areas where the sediment supply is limited. The initial erosion at Pakawau and Waikato is caused by storm wave attack removing the beach sediment.

An insufficient sediment supply means that the beaches do not restabilise before the next storm. At Pohara Beach the erosion problem is the result of its location at the updift end of a longshore transport system. Storm wave attack will greatly accelerate the beach erosion, but it is not the primary cause.

The erosion control measures instigated at Pakawau, Waikato and Pohara reflect the contrast in the understanding of the causes of the erosion problem and the effects that certain control measures will have on a particular beach environment.

The failings and successes of the various erosion control measures underline the importance of comprehensive coastal planning, which can only be attempted if the behaviour of a particular beach system is fully understood. As discussed in previous chapters a spatial and temporal variation exists around Golden Bay with respect to beach morphodynamics. Thus separate coastal management policies would be needed for each distinct coastal environment. This would decrease the likelihood of excessive extrapolation of control policies from one part of the coast to another.

CHAPTER SIX

COASTAL COMPARTMENTS

6.1 INTRODUCTION

The previous chapters have described the spatial and temporal variations in Golden Bay's beaches with respect to the sediments, morphology and dynamics and recent shoreline change. This discussion provides a base on which to propose and discuss the existence of several distinct beach compartments.

The term coastal compartment is often mentioned in the literature but the criteria that define these compartments are seldom stated. However Davies (1974) recognised the existence of these compartments and discussed their behaviour primarily in terms of the sediment budget as shown by Figure 6.1

The criteria used for defining the coastal compartments around Golden Bay are based on the information on marine environment processes, sediment characteristics, beach morphology and dynamics and the stability of the shoreline.

Davies (1974) discussed the defining of compartment boundaries and the types he identified are suitable for use in the Golden Bay situation. The boundaries of the compartments have to be drawn rather arbitrarily, but as far as possible they are most meaningfully placed where the coastline changes dramatically in terms of the above mentioned criteria. With this in mind it may be possible to envisage hierarchies of compartments of varying size and varying degrees of exclusiveness. Longshore sediment exchanges exist between various compartments around Golden

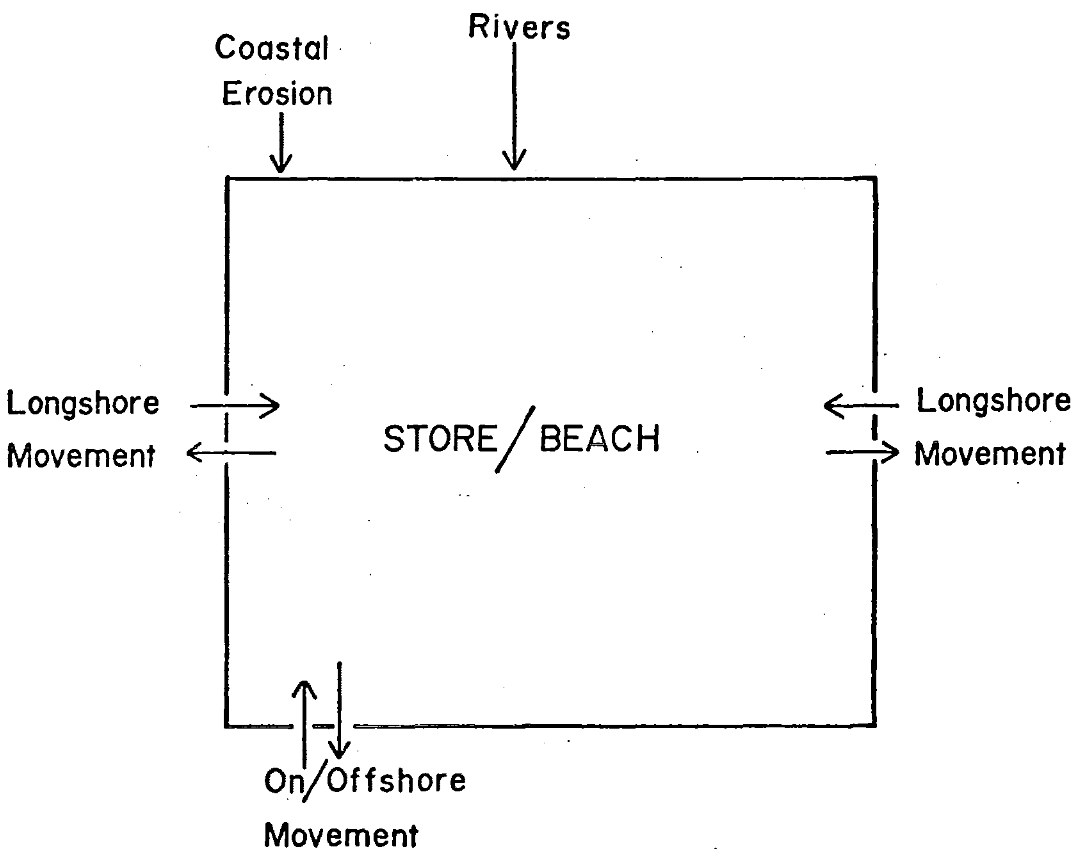

Fig. 6. 1 - Inputs and outputs of the coastal sediment system. (after Davies, 1974)

Bay and as such it was difficult to define definite longshore sediment rates for some less exclusive compartments. The various zones of sediment movement, discussed in Chapter Three, indicate that a number of separate compartments exist within these broader sediment transport zones. Therefore longshore sediment rates as proposed in the following discussion are defined on the basis of these sediment zones.

6.2 DESCRIPTION OF COASTAL COMPARTMENTS

The locations of the following compartments are shown in Figure 6.2.

I Pakawau.

This compartment includes the coastline from just north of Abel Head to the Pakawau Inlet. This section of coastline is situated in the highly refracted and diffracted zone of the Golden Bay wave environment. The very low wave energy environment is reflected in the beach morphology and dynamics. Generally the beaches are narrow in width (20 m) and are backed by a narrow backshore and very low dune cliffs. The beach is fronted by extensive tidal flats, over 1000 m wide, which have very low gradients, $\leqslant 1^{o}$ (Plates 6.1 and 6.2).

Based on local variations in beach sediments, morphology and dynamics, two less distinct cells may be identified.

The beaches in cell A are generally composed of finer sediment and show less steep beach gradients, except those beaches which contain large amounts of shell material and hence have steeper beach gradients. The beaches show a greater amount of volumetric beach change (30-40 m^3/m) over the study period.

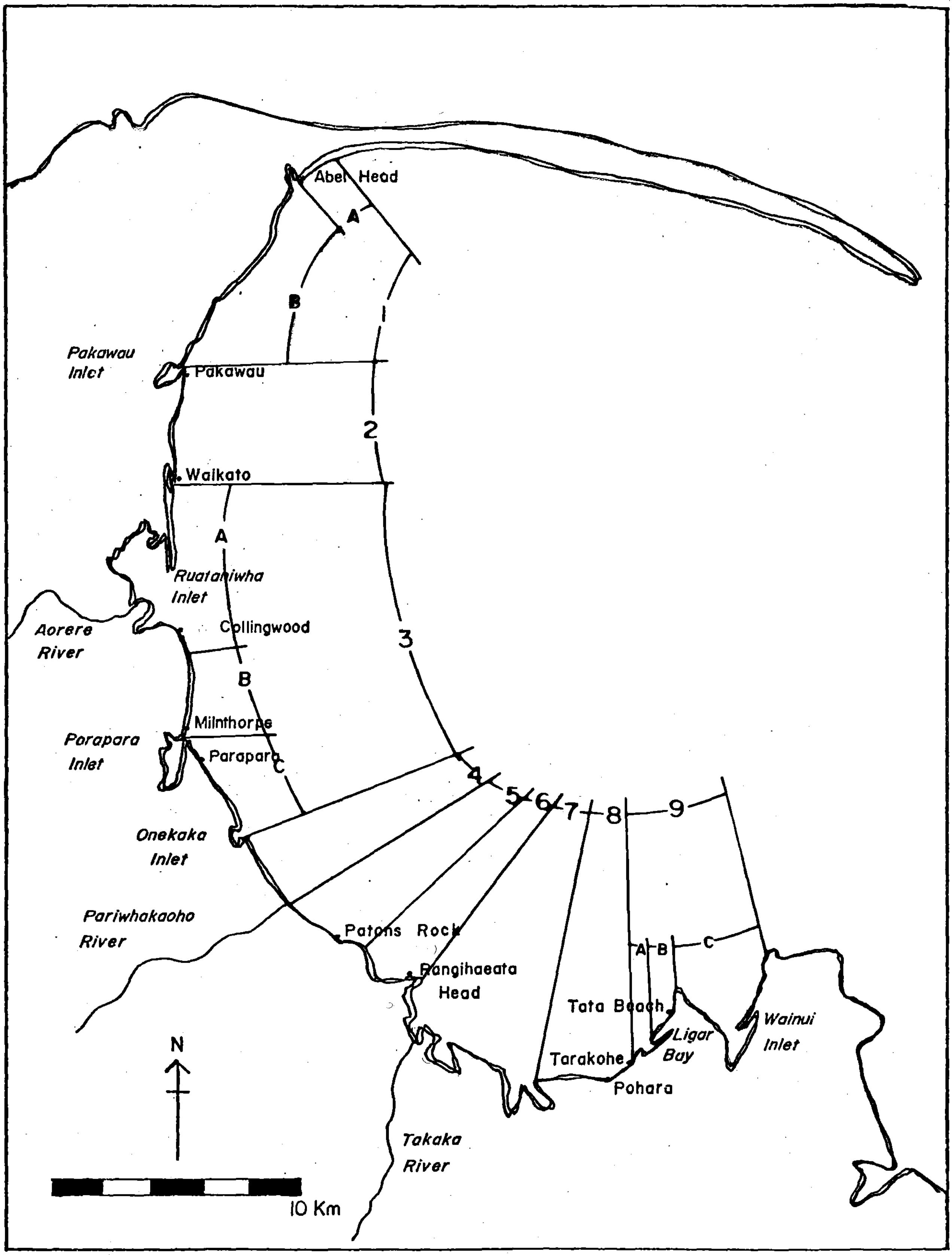

Fig. 6. 2 - Coastal compartments of Golden Bay.

Plate 6.1 - Protected beach in compartment One, cell B.

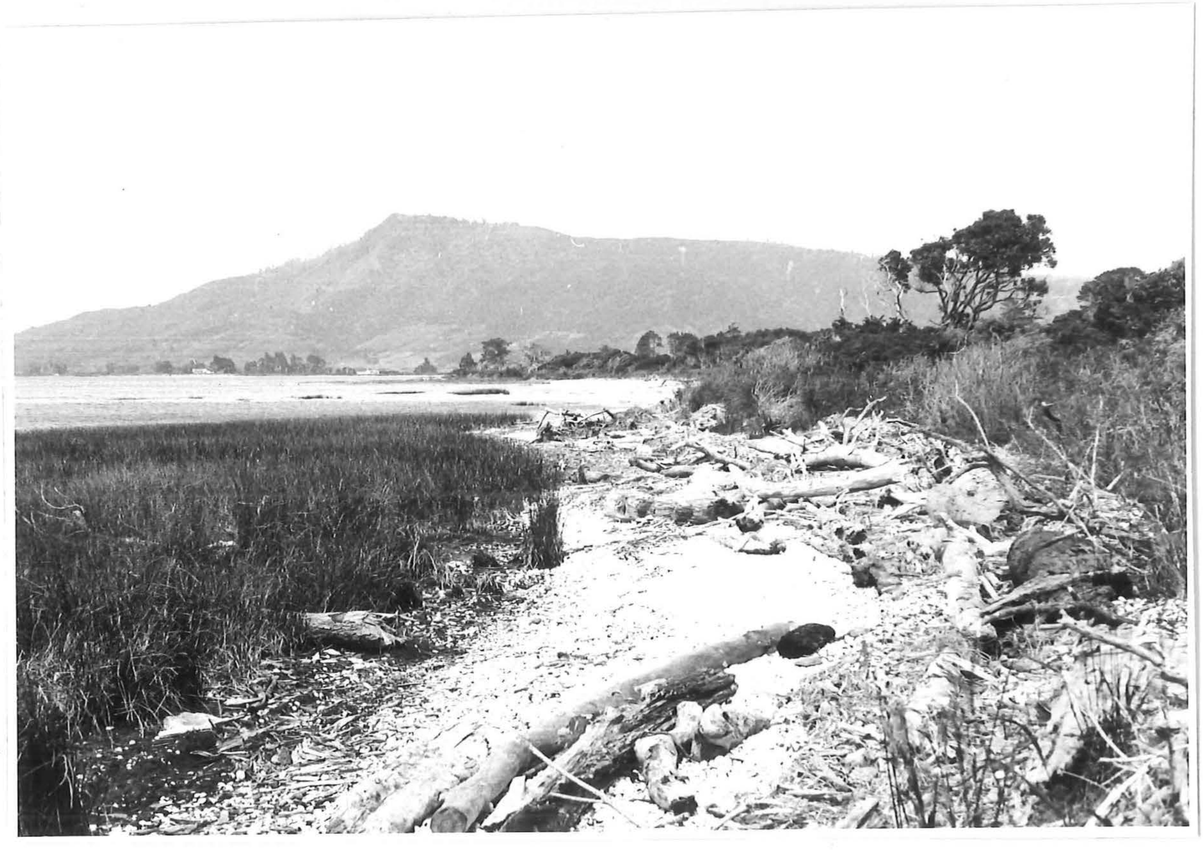

Plate 6.2 - Protected beach in compartment One, cell B.

The beaches in cell B are composed of coarser sediment which is reflected in steeper beach gradients. The coarser beach sediment is less likely to be moved by the low wave energy and hence the beaches show a low degree of volumetric change (10-20 m^3/m).

Overall the beaches in compartment I show a lower degree of volumetric beach change than beaches elsewhere in Golden Bay.

The Pakawau compartment is contained within the northern sediment zone where sediment rates are in the order of $2.7 \times 10^5 m^3yr^{-1}$. Sediment movement is predominantly in a northerly direction but beach drift will be hindered by Abel Head which will restrict longshore sediment movement from cell B into cell A. Buildup of wrack at Abel Head suggests short periods of southerly sediment movement may occur. The surveying of the beaches over the study period indicates that the beach face remains stable in relation to the amount of change occurring on the tidal flat. This suggests that the sediment is moved through the tidal flat area of the beach by the offshore circulation system with little onshore movement to the upper beach area. This is especially so in cell B where the relict gravel deposits on the beach and extensive beach vegetation restrict sediment movement.

Investigation of shoreline position changes over the recent past shows that the shoreline has been very stable with no significant periods of erosion or progradation. Thus the short term stable beach system is reflected in a longer term stable shoreline.

2 Waikato

The Waikato compartment lies between Pakawau Inlet and Waikato. The inlets at either end of the compartment act as filtering type boundaries; that is, sediment movement occurs with adjacent compartment, 1 and 3, but the overall compartment characteristics are significantly different as to allow the defining of a separate compartment.

The beaches within this compartment have beach widths of approximately 35 m, with beach gradients of 3-4^{o}. The beaches are backed by dune cliffs that vary in height from 0.5 m at Waikato to 2.0 m in the middle portions of the compartment and 1.0-1.5 m near Pakawau. The tidal flats fronting the beaches are of a steeper gradient and less extensive than those in the Pakawau compartment. Beach sediments are medium, well to moderately well sorted sands.

These beaches are exposed to a higher degree of wave energy which is reflected in volumetric beach changes in the order of 60 m^3/m, and they reflect the seasonal pattern of summer cut and winter fill identified for Golden Bay.

This compartment is also contained within the northern sediment zone, where the sediment rate is $2.7 \times 10^5\ m^3 yr^{-1}$ and predominantly in a northerly direction.

The erosion scarp on the seaward side of the foredune indicates that storm induced erosion is significant. The analysis of shoreline change shows that significant amounts of erosion have occurred in the recent past. The erosion is primarily storm induced but a notable lack of sediment from southerly sources results in beaches that are under-nourished. This indicates that the primary source of sediment, within the compartment, is from the eroding beaches and which is moved north, possibly into compartment 1. A true indication of the amount of sediment movement within this zone is unclear.

3 Collingwood

The third compartment is situated between Waikato to the north and the Onekaka Inlet to the south. This compartment is broadly defined by the criteria of shoreline stability. The adjacent compartments, 2 and 4, have shorelines that are subject to episodic or continual erosion. There exist within this zone a number of smaller cells which vary due to different circulation systems, beach sediments and morphology.

Cells A and B of this compartment are dominated by the Aorere ebb tide delta. Cell A which comprises the southward projecting spit that encloses the Ruataniwha Inlet, is dominated by a net southward drift system. Lynch-Bloose and Kumar (1976) discuss how such a spit complex may develop when the gross regional movement of sediment is in the opposite direction. The ebb current will deposit large amounts of sediment that is unable to be moved by the longshore current. As a result of this buildup of sediment a transverse bar results which protects the coastline to the north of the inlet opening from the predominant wave approach and drift direction. The bar produces a local variation in wave refraction and a secondary gyre motion in an offshore then southerly direction. This results in a spit complex projecting in an opposite direction to the predominant northward sediment drift. Analysis of shoreline change shows that the spit has grown significantly over the last 30 years.

The coastline between Collingwood and Milnthorpe, cell B, has shown a stable coastline during the recent past but it has a predominantly northward sediment movement. Sediment is supplied from the Parapara Inlet and the Aorere River.

The beach face width is between 30-50 m and is backed by a foredune which has a maximum height of approximately 3.0 m downdrift from Milnthorpe. The beach gradient is less steep near Collingwood (3^{o}) as the beach sediment is of a finer texture, while near Milnthorpe the coarser beach sediment results in a beach gradient of 6^{o}. The extent of the tidal flat is greatest near Collingwood, where the Aorere River ebb delta is developed, but becomes less expansive towards the south.

Beach volumetric changes are in the order of 60-80 m^3/m; this reflects quite a large amount of short time change while the longer term picture is one of a stable to prograding shoreline.

The beaches in cell C behave in a similar fashion to those in cell B, but a distinct cell may be defined as Parapara Spit in the north acts as a filter type boundary to sediment exchange as does the Onekaka Inlet to the south.

The beaches are composed of fine to medium grained sediment that is well sorted. The beaches are backed by low foredunes and fronted by tidal flats which extend for approximately 250 m. The amount of volumetric beach change is in the order of 60-100 m^3/m. It appears that greater change occurs in the intertidal area than on the upper beach area; thus sediment is moved through the cell in a northerly direction and only limited sediment is moved on to the beach face area.

The analysis of recent shoreline change reveals that Parapara Spit has prograded substantially. The beaches to the east act as a feeder zone for the spit but remain stable, supporting the notion that the sediment is moved along these beaches but little exchange takes place with the upper beach area.

Exact rates of sediment movement are difficult to ascertain but based on the sediment zones, previously discussed, the sediment transport rate may be approximately $1.6 \times 10^5 \ m^3 \ yr^{-1}$, predominantly moved in a northerly direction.

4 Onekaka

The Onekaka compartment lies between the Onekaka Inlet and the Pariwhakaoho River. This is essentially an erosional zone. The coastline is characterised by weak siltstone cliffs that have slowly eroded, 0.03 to 0.04 m yr^{-1} since the Holocene to produce very flat shore platforms. These platforms are only exposed at low tide and are covered by a thin veneer of fine sand.

5 Patons Rock

This compartment is bounded by the Pariwhakaoho River to the west and by Patons Rock to the east. Patons Rock may act as a block to significant longshore sediment movement from the east. Longshore sediment movement is predominantly in a westerly direction and the gross rate may be in the order of 5.0×10^4 m^3 yr^{-1}.

The beach face, which has a gradient of 3^o and a width of 30 m, is backed by low dune cliffs approximately 0.8 m high. Volumetric beach changes are in the order of 70 m^3/m. Due to sufficient sediment supply the beaches are able to adjust quickly to short term erosional changes and thus a longer term stable situation prevails on the shoreline.

6 Rangiheaeta Head

The boundaries that define this compartment, Patons Rock to the west and Rangiheaeta Head to the east, are complete obstacles to longshore sediment exchanges with adjacent compartments. This results in an insufficient sediment supply to renourish the beach system. Hence erosion has proceeded for a very long time as evident from the analysis of shoreline change. The amount of volumetric beach change is in the order of 60 m^3/m. The beach profile changes over the study period reveal a pattern identified in other compartments; that is, greater sediment exchange occurs on the tidal flat with little onshore exchanges with the upper beach area. Therefore it appears that the sediment in the beach system is continually reworked with little new sediment being supplied to the compartment.

7 Takaka

The Takaka compartment is dominated by the outflow of sediment from the Takaka and Motupipi Rivers. The sediment from the Takaka River is moved offshore and redistributed by the westerly circulation system. Little sediment is directly moved into the sixth compartment due to the Rangiheaeta Headland. However there are greater exchanges of sediment with the compartment to the east. Gross sediment movement may be in the range of $2.6 \times 10^5 m^3 yr^{-1}$ of which approximately 60% is moved in a westerly direction.

The beaches are composed of fine sediment and hence have low beach gradients (3^o). The beaches are backed by low dunes, 0.5 m high, and fronted by expansive tidal flats.

The beaches display very small volumetric changes ($14 m^3/m$) which suggests that the beaches remain very stable during the year. This is reflected in a shoreline that has shown little change over the past 30 years and so this zone may be classified as very stable (Plate 6.3).

8 Pohara

The Pohara compartment lies between the Motupipi Inlet to the west and Pohara Beach to the east.

The zone is dominated by a net westerly longshore movement of sediment that divides the compartment into a feeder zone and a trap zone. Pohara Beach is situated at the updrift end of this transport system and serious erosion problems have resulted due to this continued loss of sediment. No sediment is supplied from the east as the compartment is bounded by resistant limestone cliffs, which restrict sediment supply. Total gross sediment movement is

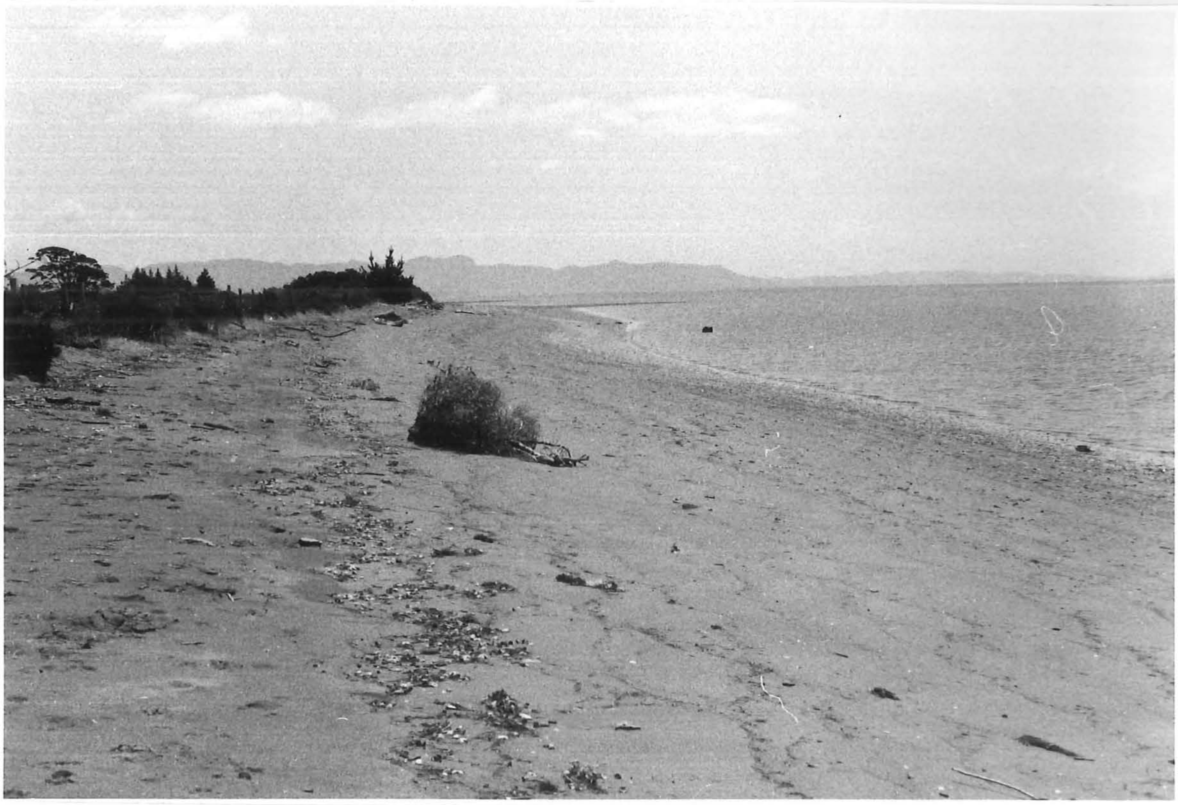

Plate 6.3 - Stable beach in compartment 7, near Motupipi River outlet.

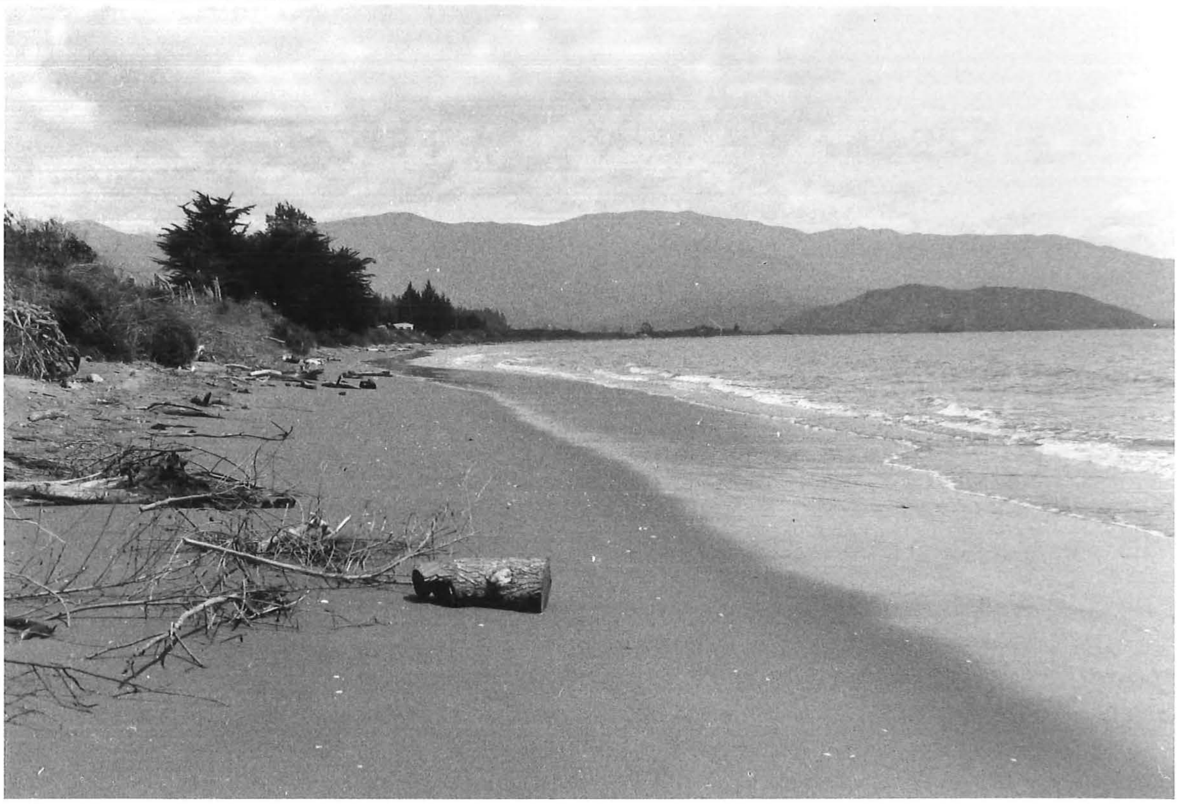

Plate 6.4 - Pohara Beach, located in the feeder zone of compartment 8.

probably in the order of $3.7 \times 10^5 m^3 yr^{-1}$ with approximately 60% being moved in a net westerly direction.

The beaches in this compartment are composed of fine well sorted sediments. The beach slopes are gentle (2-3°). The beaches are backed by dunes that increase in height downdrift from Pohara; that is, to the west. The beach profiles reflect large amounts of volumetric beach change, in the order of 70-75 m^3/m. This is a result of the high degree of exposure to wave energy and the large fluctuations in sediment supply.

The coastline in the "trap" section of the compartment has shown periods of coastline progradation. This is due to the abundant sediment supplied from the eroding Pohara Beach area and the Motupipi River. The foredune in this downdrift section of the compartment shows evidence of recent severe erosion but the abundant supply of sediment should ensure that this section of coastline remains relatively stable.

9 Wainui

The Wainui compartment is bounded by the limestone cliffs near Tarakohe (Plate 6.5) and to the east by Wainui Inlet. Within this larger exclusive compartment lie a number of smaller compartments which display similar characteristics but are mutually exclusive in terms of longshore sediment transfers.

In profile the beaches are steeply sloping (5-10°) and are backed by low sand dunes. The beach material is very coarse and is derived from the erosion of the deeply weathered granite rocks which are exposed along the shoreline in this area. All the beaches except Tata Beach (Plate 6.6) which is a tombolo formation, display a marked break of slope seaward of the beach. This break of slope is associated

Plate 6. 5 - Limestone cliffs near Tarakohe.

Plate 6. 6 - Tata Beach, cell B, compartment 9.

with a major change in sediment texture and composition. The sediments are similar to those found on offshore areas on the other beaches. This suggests that the offshore sediments may be involved in a broader circulation system than is found onshore. The coarser beach sands are limited to bay-head locations and so they have a discontinuous distribution along the shore and are not involved in a broader scale coastwise sediment transfer. Potential gross longshore transport rates for the compartment are in the order of $2.0 \times 10^5 m^3 yr^{-1}$ with a predominantly westward movement.

Within each separate cell there are periodic redistributions of beach sediment which reflects the varying incidence of north-easterly and north-westerly weather systems. At Ligar Bay, Tata Beach and Wainui Bay the net drift of sediment is in a westerly direction. This is suggested by the formation of larger dune systems on the western ends of these beaches and the growth of the spit complex in Wainui Inlet. Sand is moved in the opposite direction but only for short periods of time, Evidence for this is the spit recurve occurring on the Wainui Inlet spit.

Volumetric beach changes over the study period are in the range of 40-60 m^3/m; this is a reflection of the coarse nature of the beach sediment which is moved to a lesser degree than would be finer sediment on a beach exposed to similar wave energy.

Over the longer time scale the shoreline has displayed a very stable position which reflects the slow rate of weathering on the limestone and granite cliffs.

Therefore these beaches are stable isolated cells which have similar internal beach characteristics and sediment redistributions. There is no apparent interconnection with respect to beach sediments between the cells but they may be open in the onshore-offshore direction.

These smaller isolated cells combine to define a larger more exclusive compartment with respect to the adjacent compartments.

6.3 SUMMARY

It is apparent that the Golden Bay coastline is comprised of a number of coastal compartments, within which occur, in some instances, a number of less exclusive cells. Therefore a hierarchy of compartments exists.

The discussion has proposed nine distinct compartments, based on certain criteria, which exist within the broader Golden Bay environment. Three of these compartments contain a number of less exclusive cells. The criteria on which the compartments are defined, are marine processes, sediment characteristics, beach morphology and dynamics and stability of the shoreline. Thus a compartment may be broadly defined by a low degree of exposure to wave energy or a distinct beach morphology or an overall prograding shoreline. The smaller cells will display a common characteristic, which defines the compartment, but may behave differently in respect to beach morphology or have net local reverse drift patterns or contain distinct beach sediment.

The defining of distinct coastal compartments displays the local spatial variations that exist in the coastal environment around Golden Bay. This recognition of separate beach zones may be a deterrent to excessive extrapolation of coastal management policies from one part of Golden Bay to another.

CHAPTER SEVEN
CONCLUSION

This thesis has presented the results of an investigation into the coastal landforms of Golden Bay, principally the modern beach environment. It has been possible to identify several distinct beach compartments, based on a variety of criteria. Thus research was conducted with the following objectives.

(1) To describe the characteristics of the physical process environment with special reference to the wind and wave climate and the longshore transport system.

(2) To study the spatial variation of the shoreline beach sediments and beach morphodynamics.

(3) To investigate any shoreline change that may have occurred in the recent past, up to 100 years before present.

(4) To propose and describe any distinct shoreline compartments that may be evident as a result of the investigation into the former three objectives.

To satisfy the above objectives a number of specific investigations were carried out. First, major field investigations included the collecting of beach sediments, the regular profiling of a number of beach locations and the noting of major spatial variations in shoreline morphology.

Secondly, the investigation into the wind and wave climate and longshore transport systems was carried out by the analysis of wind and wave data and the construction of wave refraction diagrams.for the significant wave producing environments.

Finally the investigation into recent shoreline change was completed by an analysis of air photographs and Survey and Deposited Plans of the Golden Bay area for various time periods.

The various investigations have been successful in two main areas. First, and most importantly, the information obtained on the spatial and temporal variations in beach processes and responses has enabled a fairly comprehensive categorisation of the Golden Bay coastline into its distinct coastal compartments. Secondly, the investigation into the criteria that made it possible to define these compartments, such as beach sediments and morphodynamics, has revealed significant information on beach behaviour. For example, distinct seasonal patterns of cut and fill, different from those commonly identified in the literature, were observed for Golden Bay; and how beaches behave in low energy macrotidal marine environments. These and other major findings will be outlined in the following section.

7.1 SUMMARY OF MAJOR FINDINGS

The Study Area

Golden Bay is a broad, shallow, roughly circular embayment over 30 km across which opens into Cook Strait. Depths within the bay do not exceed 40 m and the shoreline is formed by a narrow strip of prograded beach ridges broken by headlands, river mouths and a number of inlets.

The pre-Quaternary geology has contributed significantly to the character of the present-day coastline by providing the structural framework on which present-day processes operate. Geologic investigations carried out in the offshore zones off the north-west coast of the South Island suggest a sea level approximately 100 m below its present position about 18-20,000 years ago. Sea level began to rise rapidly from this period to about 4-7000 years ago when it began to stabilise about its present position. Since the stabilisation period the coastline has adjusted itself by the growth of spit complexes and the erosion of post-glacial shoreline features.

The climatic situation is dominated by the presence of strong westerly winds which accompany the passing of anticyclones to the north of the area.

The offshore circulation pattern of the current system in Golden Bay is primarily in a clockwise (westerly) direction. The tidal flow in Golden Bay is diurnal and the tidal range and the difference between spring and neap tidal ranges are amongst the largest in New Zealand. The tidal range is in the order of 5.0 m while the difference between spring and neap tidal ranges is approximately 1.8 m.

Coastal Processes

An investigation into the magnitude, frequency and significance of the dominant coastal processes identified the following main features.

The major feature to emerge from the wind and wave data is the large proportion of the time that winds blow from a direction and at a speed that results in very calm sea conditions; that is, 70% of the time.

A distinct seasonal pattern is evident that is contrary to the usual seasonal cycle identified in the literature. The spring-summer months are periods of rougher sea conditions which may result in beach erosion. The autumn-winter period is characterised by calmer wind and wave conditions that may result in periods of beach accretion.

Sea level variations are likely to occur over a very short period of time and are of a significant magnitude as to create serious erosion problems. The water elevation may be in the order of 1.8 m if due to storm surges and coupled with wave setup and the occurrence of spring tides.

Wave energies are low in Golden Bay compared to exposed open-ocean shores elsewhere in New Zealand. It appears there are two storm wave components. North-easterly storm waves generated in Cook Strait are the result of storm systems moving south off the west coast of the North Island. Secondly, strong north-west winds produce short steep waves generated within Golden Bay over a 30 km fetch. These waves are highly erosive. Generally the northern part of Golden Bay is subject to much lower wave energies due to the high degree of refraction and diffraction that occurs to the wave regimes. The southern areas of the Bay receive a higher concentration of wave energy.

The northern sediment transport cell of Golden Bay has a predominant northerly movement of sediment that is generally moved by north-west waves. Sediment movement in the central and southern cells is predominantly in a westerly direction and by north-east waves. The sediment transport rates and directions proposed are purely theoretical and significant local variations may exist.

Coastal Sediments and Morphology

This investigation has revealed the spatial and temporal variations in the coastal sediments and beach morphodynamics.

The beach sediments are predominantly medium to fine sands which are well to very well sorted. Local deviations from these characteristics result from local sediment sources, such as granite cliffs and relict gravel deposits. The percentage of calcium carbonate material varies from 1.0 to 47.0%, with the beaches in the northern part of Golden Bay containing larger amounts. The degree of sorting of the beach sediment varies according to original source characteristics and hydraulic factors such as variations in wave energy.

Beach morphology and dynamics reflect the beaches' sediment composition and degree of exposure to wave processes. The beaches in the northern part of Golden Bay remain relatively more stable than the beaches in the more exposed southern sectors. Volumetric beach changes on the protected northern beaches were in the order of 20-40 m^3/m while volume changes on the southern beaches were typically 40-80 m^3/m. These significant amounts of short term beach change are a function of appreciable short term sea level rises and acoompanying wave conditions.

Overall the beaches reflected a spring-summer cut profile and a stable to accreting profile in the autumn-winter. This seasonal pattern is quite different to that identified on open-ocean swell environments where the pattern is the reverse of the Golden Bay situation.

Recent Shoreline Change

Historical coastal change, determined from air photographs and Survey and Deposited Plans, shows that the greater percent of the exposed shoreline is stable to prograding. Only 9.0kms of the total exposed shoreline is subject to periods of erosion.

The stable to prograding sections of the coastline are generally in receipt of abundant sediment supply. The major areas of erosion are where the sediment supply is limited. The initial erosion of the shoreline may be triggered by severe storm waves and the insufficient sediment supply will result in undernourished beaches. At other places, for example Pohara Beach, the erosion is primarily induced by lack of sufficient sediment supply and the incidence of storm waves only accelerates the erosion rate.

The erosion control measures instigated to stabilise the coastline reflect the contrast in the amount of prior investigation into the causes of the erosion problem. The problems at Pakawau and Waikato were not fully researched and this has resulted in control measures that compound the problem. In contrast the problem at Pohara has been extensively researched and thus control measures are being instigated that function in harmony with the processes of the beach system.

Coastline Compartments

The identification of beach compartments for the Golden Bay shoreline has resulted in the recognition of a hierarchy of compartments.

Nine distinct larger compartments were identified, three of which contain a number of smaller less distinct cells. The larger compartments were defined according to dominant criteria, while the smaller cells may display different beach characteristics. They have a common controlling factor that defines their existence within the larger compartment.

The defining of compartments has displayed the local spatial variations that exist in the coastal environment; no one beach system is completely similar to another. Thus this recognition of separate beach compartments may be a deterrent to excessive extrapolation of management policies from one part of Golden Bay to another.

7.2 SUGGESTIONS FOR FURTHER RESEARCH

The research for this thesis is the first attempt to comprehensively study spatial and temporal variations in beach sediments and morphodynamics and define the extent and function of beach compartments in Golden Bay. Because of this the research has been on a wide base. Thus certain coastal features have not been intensively researched.

Future research could be usefully carried out on the evolution of the various spit complexes and their comparative dynamics. Similarly, investigations of the formation and behaviour of the numerous estuaries and inlets would be interesting.

More detailed investigations into the behaviour of the beach compartments over a longer period of time would be of benefit to coastal planning. Sediment supply rates, dispersal rates and directions of movement would also be valuable information for coastal planning. As Golden Bay is a prime holiday area and future developments of the coastline is to be expected, a comprehensive report pertaining to coastal management is of prime importance.

REFERENCES

ANDREWS, P.B. and VAN DER LINGEN, G.J. (1969). Environmentally significant sedimentologic characteristics of beach sands. New Zealand Journal of Geology and Geophysics, 12: 119-137.

BISHOP, D.G. (1971). Sheet S1, S3 and Pt. S4, Farewell-Collingwood Geological map of New Zealand. 1 : 63,360, DSIR, Wellington.

BERGQURST, R.P. and others (1975). Marine environment of Golden Bay. Report Prepared by Members of the Zoology and Geology Departments of the University of Auckland for Shell BP and Todd Oil Services Ltd. 98p.

BIRD, E.C.F. (1976). Shoreline changes during the past century. Preliminary review for International Geographical Union Working Group on the Dynamics of Shoreline Erosion. 23rd International Geographical Congress, Moscow. 54p.

BRODIE, J.W. (1960). Coastal surface currents around New Zealand. New Zealand Journal of Geology and Geophysics, 3: 235-252.

BRUUN, P. (1962). Sea level rise as a cause of shore erosion. American Society of Civil Engineering Proceedings, Journal of Waterways. Harbours Division, 88: 117-130.

COASTAL ENGINEERING RESEARCH CENTRE (1973). Shore protection tion manual, 3 volumes. United States Army, CERC.

CURRAY, J.R. (1964). Transgressions and regressions. In Miller, R.J. Papers in marine geology. New York, MacMillan, 175-203pp.

CHAPPELL, J. (1975). Upper Quaternary warping and uplift rates in the Bay of Plenty and west coast, North Island, New Zealand. New Zealand Journal of Geology and Geophysics, 18(1): 127-155.

DAVIES, J.L. (1972). Geographical variation in coastal development. Edinburgh, Oliver and Boyd. 204p.

DAVIES, J.L. (1974). The coastal sediment compartment. Australian Geographical Studies, 12(2): 139-151.

DAVIS and others (1972). Comparison of ridge and runnel systems in tidal and non-tidal environments. Journal of Sedimentary Petrology, (2): 413-421.

DUBOIS, R.N. (1975). Support and refinement of the Bruun rule on beach erosion. Journal of Geology, 83: 651-657.

DUBOIS, R.N. (1976). Nearshore evidence in support of the Bruun rule on shore erosion. Journal of Geology, 84: 485-491.

FOLK, R.L. (1974). Petrology of sedimentary rocks. Austin, Texas, Hemphills. 182p.

GARNIER, B.J. (1958). The climate of New Zealand. London, Arnold. 191p.

GIBB, J.G. (1978). Rates of coastal erosion and accretion in New Zealand. New Zealand Journal of Marine Freshwater Research, 12(4): 429-456.

? 1979

GILLIE, R.D. (1972). Sand and gravel deposits of the coast and inner shelf east coast, Northland Peninsula, New Zealand. Christchurch, University of Canterbury. 328p. (Thesis: PhD. Geography)

GRINDLEY, G.W. and WATTERS, W.A. (1965). Geology of Nelson, In National Resources Survey, part IV Nelson region, Chapter 3, geology. Wellington, Government Printer. 21p.

GRINDLEY, G.W. (1971). Sheet S8, Takaka. Geological map of New Zealand. 1 : 63,360, DSIR, Wellington.

HEALY, T.R. (1978). Beach surveys. In Bay of Plenty, coastal erosion survey, report 78/2, Bay of Plenty Catchment Commission.

HEATH, R.A. (1969). Drift card observations of currents in central New Zealand region. New Zealand Journal of Marine Freshwater Research, 3(1): 3-12.

HEATH, R.A. (1973). Meteorological effects on the surface circulation and hydrology of Tasman Bay, New Zealand. New Zealand Journal of Marine Freshwater Research, 7(1 and 2): 111-123.

HEATH, R.A. (1976a). Circulation and hydrology of Tasman Bay. New Zealand Oceanographic Institute Summary No. 10. 8p.

HEATH, R.A. (1976b). Circulation in Tasman Bay. New Zealand Journal of Marine Freshwater Research, 10(3): 469-483.

HEATH, R.A. (1977). Significance of storm surges on the New Zealand coast. New Zealand Oceanographic Institute paper. 13p.

KANA, T.W. (1977). Beach erosion during minor storms. American Society of Civil Engineering Proceedings, Journal of the Waterway Port Coastal and Ocean Division, 103(WW4), Nov: 505-519.

KING, C.A. (1972). Beaches and coasts. 2nd ed. London, Arnold, 570p.

KIRK, R.M. (1975). Unpublished compilation of late Quaternary sea level fluctuations around New Zealand. 2p.

KIRK, R.M. (1977a). Coastal zone erosion problems. Paper presented to Environment '77 Conference. Christchurch, 16p.

KIRK, R.M. (1977b). Coastal evolution and stability in the Parapara Spit complex, Golden Bay. In Transport Nelson Ltd., Proposed development Parapara, Golden Bay, JASMAD Group Ltd, Appendix 2, 14p.

KIRK, R.M. (1978a). Unpublished report to Department of Lands and Survey, Nelson on foreshore erosion and shoreline stability at Pohara Beach, Golden Bay. 11p.

KIRK, R.M. (1978b). Unpublished report on disposal of dredge and spoil at Tarakohe and coastal erosion at Pohara Beach for Morris and Wilson. 39p.

KIRK, R.M. (1979). Morphology, processes and sediments of mixed sand gravel beaches. In press.

LYNCH-BLOSSE, M.A. and KUMAR, N. (1976). Evolution of down-drift-offset tidal inlets; a model based on the Brigantine Inlet system of New Jersey. Journal of Geology, 84: 165-178.

MARINE DIVISION, Ministry of Transport, New Zealand (1979). New Zealand tide tables for the year 1979.

McLEAN, R.F. (1978). Recent coastal progradation in New Zealand. In Davies, J.L. and Williams, A.J. Landform evolution in Australasia. London, Arnold. 168-195pp.

McLEAN, R.F. and KIRK, R.M. (1969). Relationship between grain size, size-sorting and foreshore slope on mixed sand-shingle beaches, New Zealand. Journal of Geology and Geophysics, 12(1): 138-155.

MORRIS AND WILSON COMPANY (1976). Environmental impact assessment of proposed harbour development and cement loading improvements at Tarakohe, Golden Bay, New Zealand. Morris and Wilson Consulting Engineers, Christchurch and Auckland.

NORRIS, R.M. (1972). Shell and gravel layers, western continental shelf, New Zealand. New Zealand Journal of Geology and Geophysics, 15(4): 572-589.

RIDGWAY, N.M. (1977). Currents and hydrology in Tasman and Golden Bay, South Island, New Zealand. New Zealand Journal of Marine Freshwater Research, 11(1): 95-109.

SCHOFIELD, J.C. (1977). Late Holocene sea level, Gilbert and Ellice Islands, west central Pacific Ocean. New Zealand Journal of Geology and Geophysics, 20(3): 503-529.

SCHWARTZ, M.L. (1967). The Bruun theory of sea level rise as a cause of shore erosion. Journal of Geology, 75(1): 76-92.

SCHWARTZ, M.L. (1968). The scale of shore erosion, Journal of Geology, 76: 508-517.

THOM, B.G. (1973). The dilemma of high interstadial sea levels during the last glaciation. In Progress in geography, international reviews of current research, Volume 5. London, Arnold.

VAN DER LINDEN, W.J.M. (1968). Off-shore sediments, northwest Nelson, South Island, New Zealand. New Zealand Journal of Geology and Geophysics, 12: 87-103.

APPENDIX ONE

PARTICLE SIZE SCALE

Millimetres	∅ units	Wentworth Scale	
256	-8	Boulders	
64	-6	Cobbles	
16	-4	Large pebbles	GRAVEL
4.0	-2	Small pebbles	
		Granules	
2.0	-1		
		Very coarse sand	
1.0	0		
		Coarse sand	
0.50	1		
		Medium sand	SAND
0.25	2		
		Fine sand	
1.125	3		
		Very fine sand	
0.0625	4		
		Silt	
0.0039	8		MUD
		Clay	

(Source: Folk (1974, p. 25))

APPENDIX TWO

GRAIN SIZE PARAMETERS
(after Folk, 1974)

Graphic Mean

$$M_z = \frac{(\phi16 + \phi50 + \phi84)}{3}$$

Inclusive Graphic Standard Deviation

$$0_I = \frac{\phi84 - \phi16}{4} + \frac{\phi95 - \phi5}{6.6}$$

Inclusive Graphic Skewness

$$Sk_I = \frac{\phi16 + \phi84 - 2\phi50}{2(\phi84 - \phi16)} + \frac{\phi5 + \phi95 - 2\phi50}{2(\phi95 - \phi5)}$$

Graphic Kurtosis

$$K_G + \frac{\phi95 - \phi5}{2.44\,(\phi75 - \phi25)}$$

Where $\phi16$, $\phi50$, etc. are the phi values of the 16th, 50th, etc percentile taken from the cumulative size distribution curve.

Verbal Classification Scales (ϕ units)

Inclusive Graphic Standard Deviation (Sorting)

<0.35	very well sorted
0.35-0.50	well sorted
0.50-0.71	moderately well sorted
0.71-1.0	moderately sorted
1.0 -2.0	poorly sorted
2.0 -4.0	very poorly sorted
>4.00	extremely poorly sorted

Inclusive Graphic Skewness (Asymmetry)

+1.00 to +0.30	strongly fine-skewed
+0.30 to +0.10	fine-skewed
+0.10 to -0.10	near symmetrical
-0.10 to -0.30	coarse-skewed
-0.30 to -1.00	strongly coarse-skewed

Graphic Kurtosis (Peakedness)

<0.67	very platykurtic
0.67-0.90	platykurtic
0.90-1.11	mesokurtic (normal curve = 1.00)
1.11-1.50	leptokurtic
1.50-3.00	very leptokurtic
>3.00	extremely leptokurtic
